GLEANINGS IN SCIENCE

"The great scientific men are all so eager in advance that they have no time to popularise their discoveries, and if we can glean after them a little, and make pictures of the things which Science describes, we shall find the service a worthy one."—Ruskin.

GLEANINGS IN SCIENCE

A SERIES

OF

POPULAR LECTURES ON SCIENTIFIC SUBJECTS

BY

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Felix qui potuit rerum cognoscere causas

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TO MY

ALMA MATER,

ST. PATRICK'S COLLEGE, MAYNOOTH,

I Dedicate this Book

AS A SMALL TOKEN

OF MY

AFFECTION AND GRATITUDE.

PREFACE.

IT has long been the practice of the Royal Dublin Society to provide, each year, for its Members, and for the general public, a Course of Popular Lectures on subjects of Scientific interest. I have been invited, from time to time, to take part in carrying out this work; and some of the Lectures I have given in connexion with it are collected in the present Volume. A Lecture is added on the Glaciers of the Alps, which partakes of the same character, but was given on a different occasion.

In preparing these Lectures for publication I have not hesitated to avail myself of materials which have come into existence since the Lectures were delivered: my desire being to lay before my readers the latest available information, and to follow out the progress of scientific discovery down to the present date. The Lectures, therefore, do not appear, in all respects, as they were

originally given; but rather as they would now be given, in similar circumstances, to a similar audience.

I have endeavoured to supply, in some measure, the place of Experiments, by means of Illustrations introduced into the text. Some of these Illustrations represent instruments or apparatus of historical interest which are already familiar to the scientific public; but most of them have been specially drawn, for the present work, from the apparatus used in my own Experiments. I am indebted to the kindness of Mr. Whymper for the four woodcuts which illustrate the last Lecture in the Volume, and which are taken from his well-known and attractive Scrambles amongst the Alps.

G. M.

October 15, 1888.

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THE

MODERN THEORY OF HEAT

AS ILLUSTRATED BY THE

PHENOMENA OF LATENT HEAT.

TWO LECTURES

DELIVERED IN THE THEATRE OF THE ROYAL DUBLIN SOCIETY,

APRIL, 1880.

LECTURE I.

THE LATENT HEAT OF LIQUIDS.

LECTURE II.

THE LATENT HEAT OF VAPOURS.

LECTURE I.

THE LATENT HEAT OF LIQUIDS.

THE Modern Theory of Heat is, I am inclined to think, the most important contribution that the present age has made to the advancement of physical science. Other discoveries might, no doubt, easily be named, which are more striking for their novelty, or more attractive for their evident and immediate usefulness. But there is no other that leads us so straight and so far into the secret mysteries of Nature; no other that seems destined to become, in future times, so fruitful a source of new discoveries.

I could not hope, within the limits of one or two popular lectures, to set forth this theory with any degree of completeness. But I thought it would not be uninteresting if I were to offer you some general conceptions regarding the theory itself, and then illustrate it by some one particular class of phenomena. For this purpose I have chosen the phenomena of Latent Heat; and my choice has this, at least, to recommend it, that if I should fail to interest you in the theory itself, I shall be able to set before you a series of facts which are full of interest on their own account, and which, if not already familiar to you, will constitute a valuable addition to your existing stores of knowledge.

Heat a Form of Energy.—A general idea of the modern theory of Heat may be conveyed in a few words. Heat is a kind of energy; it may be converted into other kinds of energy; and other kinds of energy may be converted into heat. Moreover, whenever heat begins to exist where none has existed before, energy of some other kind must be expended in producing it; and whenever heat is expended and ceases to exist, some other kind of energy, its exact equivalent in amount, must at the same moment begin to exist.

It will help us to form a more distinct conception of this dry and summary statement, if we consider one or two methods by which heat may be produced. Everyone knows that a smith can take a bar of cold iron, lay it on a cold anvil, and make it red hot by repeated blows from a cold hammer. Now, where does the heat come from that is developed in this process? The modern theory answers that the energy of the moving hammer has been converted into the energy of heat. Each time that the hammer descends, it possesses a certain energy of motion, capable of giving a blow; but the moment the blow is struck, the hammer is stopped in its course, and has lost the energy it possessed before. Nevertheless this energy has not been absolutely destroyed; it has only been converted into a new form; and it now exists as heat. The motion of the hammer has been, in fact, transferred to the molecules of the iron bar—that is, the indefinitely small particles of which the iron bar is made up—and these molecules are now swinging about, with a certain degree of activity, through indefinitely small spaces. This swinging motion of the molecules is the objective

physical fact that constitutes what we call the heat of the bar. As the blows of the hammer are repeated, the motion becomes more and more energetic, and the bar gets hotter and hotter. If, on the other hand, the bar is left to itself, the motion gradually gets feebler, and the bar gets colder.

Thus, according to the modern theory, heat is a kind of energy, and that energy consists in a swinging to and fro of the molecules of the hot body; whereas according to the old theory, which prevailed very generally down to the close of the last century, heat was regarded as a kind of matter. It was conceived to be a subtle and elastic fluid, without weight, which could be added to a body, or taken away from it, by various means. If it was added, then, as a general rule, the body got hotter; if it was taken away, the body, as a general rule, got colder. The particular example to which I have just referred offered some difficulty to the advocates of this theory; because it was not easy to see where this subtle fluid comes from, each time that the smith's hammer strikes the iron bar. They suggested, however, that the heat thus developed already existed in the iron bar: but it was not sensibly felt, because it was hidden, in some way, between the particles of the mass, and the effect of the blows was simply to force it out from its lurking-places, and to make it sensible.

Count Rumford's Experiment.—Another example of the production of heat which brings these two theories very clearly before us, in striking contrast, is furnished by the classical experiment of Count Rumford, which was made at the very close of the last century. He was engaged, at the time, in superintending the boring of cannon in the military

arsenal at Munich, and he was forcibly struck by the immense amount of heat that was developed in the small shavings of metal cut away by the action of the boring instrument. In particular, he called attention to the fact that the quantity of heat which might be generated by this process, in the same mass of gun-metal, seemed practically inexhaustible. Now you will see that, if heat is a material substance, the quantity of that substance contained in a given mass of gun-metal, and capable of being squeezed out of it by any process, must be limited; whereas if it is a swinging to and fro of the molecules, produced by the pressure of the gun-metal as it rotates against the edge of the boring instrument, then the quantity of this motion depends simply on the quantity of energy expended in producing such pressure. Hence Count Rumford argued that the development of heat, in the process of boring cannon, told very strongly against the supposition that heat is a kind of matter, and in favour of the supposition that heat is a kind of motion.

With a view to exhibit this phenomenon in a striking light, he devised the experiment to which I have referred. A cylinder of metal, partially bored, was so mounted that it could be made to rotate round its axis, and, in rotating, to press against the edge of the boring instrument, which was firmly held in a fixed position. The cylinder was then enclosed in an oblong deal box, and the box was filled with cold water. The weight of the metal cylinder was 113 pounds, and the quantity of water surrounding it was two gallons and a-half. The apparatus was then set in action; the metal cylinder began to revolve, pressing always against

the edge of the steel borer, and in two hours and a-half that large quantity of water was actually boiled by the heat that was generated. "The result of this beautiful experiment," writes Count Rumford, "was very striking, and the pleasure it afforded me amply repaid me for all the trouble I had had in contriving and arranging the complicated machinery used in making it ... It would be difficult to describe the surprise and astonishment expressed in the countenances of the bystanders, on seeing so large a quantity of water heated, and actually made to boil, without any fire. Though there was nothing that could be considered very surprising in this matter, yet I acknowledge fairly that it afforded me a degree of childish pleasure which, were I ambitious of the reputation of a grave philosopher, I ought most certainly rather to hide than to discover."

On the table before you is an apparatus with which a somewhat similar experiment may be made, on a much smaller scale, but also, I may add, in a much shorter time. You see this hollow cylinder of copper, about three inches long, and less than half an inch in diameter, mounted on a whirling table. I pour into it a little water, at the temperature of this room, and close the cylinder with a cork. Next I take two oak boards, fastened together at one end by a hinge, and folding them round the copper cylinder, I grasp it between two semicircular grooves, which are cut on the inside of the boards. My assistant will now turn the wheel of the whirling table; the cylinder is made to rotate between the oak boards, which are pressing against it; you see what energy he must expend to overcome the resistance they offer. But, while that energy is passing away, heat is developed in

the cylinder, and this heat gradually passes to the water within it. Meanwhile it is evident my assistant is getting tired; the steady resistance of friction is too much for him; he is not working with the freshness with which he began;

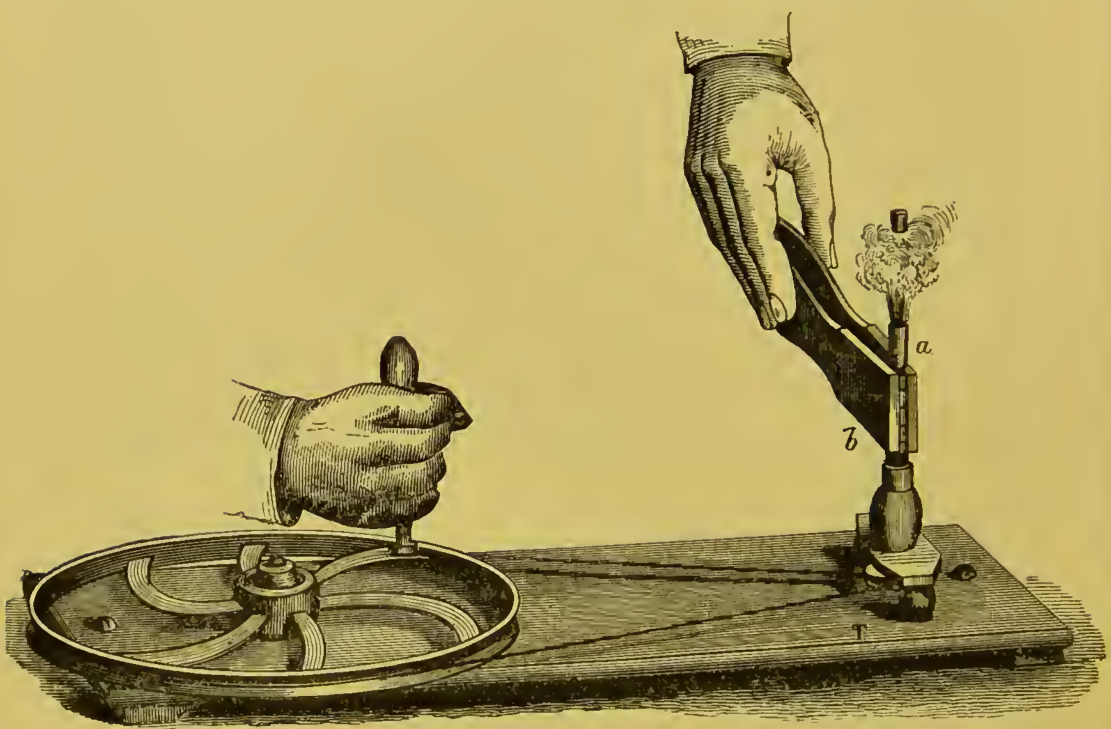

FIG. 1.

HEAT PRODUCED BY EXPENDITURE OF MECHANICAL ENERGY.

T Whirling Table.
a Hollow Copper Cylinder.
b Oak Boards, hinged at one end, and closed on Copper Cylinder.

and another must take his place. At the end of about two minutes, the water begins to boil, steam is formed within the cylinder, and now the cork is driven out with a sort of mild explosion, and is followed by a puff of steam.

Where did the heat come from that boiled the water in this experiment? Those who used to think that heat was a

kind of matter, could only say that this matter must have been there from the beginning; that it was hidden, at first, in the little spaces between the molecules, and that it was then squeezed out by the pressure of the oak boards. But the modern theory tells us that the muscular energy expended in turning the wheel has been converted into the energy of heat in the copper cylinder. The rotating motion of the cylinder, according as it was checked by the resistance of friction, was converted into a swinging motion of its molecules to and fro; and this swinging motion of the molecules was itself the heat of the cylinder, and passed, in due course, from the cylinder to the water it contained.

In making this experiment I always feel as if somebody would say that, after all, it is much ado about nothing; that I have tired two men, and boiled a thimblefull of water. But this is really one of the most instructive features of the experiment; for it teaches us that the small quantity of heat required to boil a thimblefull of water is the equivalent of a very large amount of muscular energy; and you see this truth illustrated every day, after another fashion, when heat is itself employed as a source of mechanical energy. The heat that is generated by the combustion of a few pounds weight of coal, in a locomotive, has an energy sufficient to transport a long train of carriages, with passengers and merchandize, over a distance of many miles.

One more example I should like you to consider, because it exhibits the production of heat from a somewhat different point of view. Here is a spiral of platinum wire, mounted between the two binding screws of a little apparatus, called a commutator, by means of which I can send an electric

current at pleasure, through the platinum spiral, from a battery near at hand. Directly I do so, heat is produced in the wire, and it glows with a brilliant light. Once again, the question forces itself upon us, Where has this heat come from? And the question becomes especially difficult, in the present instance, because the nature of the electric current is so entirely unknown to us. If we were to regard heat as a kind of matter, I really think we could offer no satisfactory account of this phenomenon: we should be obliged to shelter ourselves behind the mysterious nature of electricity, which can do so many things that we cannot explain. But if we regard heat as a kind of energy, there is no difficulty in accounting for its production in the experiment before us. It is true we do not know what the electric current is, in its intrinsic nature; but we are certainly justified in believing that it has some kind of energy, because it can do work of various kinds. Now we know that the current is transmitted through the platinum wire; that it there encounters resistance; that it overcomes this resistance, and that, in doing so, it expends a portion of its energy; and we say that the energy so expended is converted into heat.

Latent Heat: Black's Experiments.—And now that we have before us, as I hope, a clear idea, though a very limited one, of the modern theory of heat, perhaps you will expect that I am going to prove it for you. But this it would be impossible to do within the limits assigned to me in these lectures. The true test of a theory, in physical science, is to bring it face to face with the facts of nature, to see if it is consistent with these facts, and if it can help us to explain them. Now, you will readily believe that where the facts

are so various, so subtle, so complex, as they are in the case of heat, the application of such a test must be the work not of hours, but of years. And even the knowledge, which I suppose is all you would aspire to, of the results arrived at by those who, with great care and labour, have applied this test to all the various phenomena of heat, must be the slow growth of time, the ripe fruit of long study. You cannot hope, then, to-day to grasp in its fulness the proof by which the modern theory of heat has been established. Nor do I mean to set it before you with any attempt at completeness. I have hinted at it more than once in explaining, by examples, the meaning and significance of the theory itself, and I now propose to develop it, somewhat in detail, with reference to that particular class of facts which are comprised under the general designation of Latent Heat.

The phenomena of Latent Heat were first investigated by Dr. Black, of Edinburgh, just a hundred and twenty years ago. His attention was arrested by the fact that when ice begins to melt it is impossible to raise its temperature, it is impossible to make it warmer, however much heat may be added to it, until all the ice is melted. If I take a quantity of snow or pounded ice, at zero Centigrade, that is, at freezing point,[1] and put it into a vessel over a spirit lamp, heat passes rapidly into the ice and melts it; but a

[1] It may be well to explain that, throughout these lectures, I find it convenient to refer to the Centigrade thermometer, which is generally adopted by scientific men, rather than to the Fahrenheit thermometer, which is more commonly used in these countries. In the Centigrade thermometer freezing point is marked nought or zero, boiling point is marked 100, and the space between them is divided into 100 equal parts, which are called degrees Centigrade.

thermometer resting in the mixture of ice and water shows no tendency to rise; it remains steadily at 0° C. until all the ice is melted. Noting this fact, and brooding over it, Dr. Black asked himself the question, What becomes of all the heat that is thus added to the melting ice, and that produces no sensible effect in heating it?

With a view to answer this question, he first proceeded to measure the *quantity* of heat that thus disappears, when a certain quantity of ice, say a pound weight, is melted. His experiments are well worthy of being recorded. He took a pound weight of water at 0° C., and a pound weight of ice at 0° C., and placing them separately in similar glass vessels, he suspended the two vessels in a chamber, the temperature of which was carefully kept uniform, at about 18° C. The water receiving heat from the surrounding air began to get warm; the ice began to melt. At the end of half an hour the water had reached a temperature of 4° C.; but not until the end of ten hours and a-half did the ice reach the same temperature, having been, of course, in the meantime melted.

Now let us try and realize the significance of these facts. To measure any quantity, we must first agree on some unit of measurement. Thus cloth is measured by the yard; distance on a railway is measured by the mile; liquids are measured by the pint, or by the gallon. So, too, when we want to measure quantities of heat, we must agree upon some unit in which such quantities may be expressed. Several units of this kind are in use among scientific men; just as there are various units of length, and various units of weight. But the unit most convenient for us, just now, is what I may call the Pound-Centigrade unit; that is, the

quantity of heat that is necessary to raise a pound weight of water through one degree of the Centigrade scale.

In the experiment of Dr. Black, which I have just described, it is evident that the pound weight of water received four such units in half an hour; because it was raised from 0° C. to 4° C., that is, through four degrees of the Centigrade scale. Now, Dr. Black reasonably assumed that the ice received the same quantity of heat, in each half hour, as the water received, because it was placed in exactly the same condition with regard to the surrounding air; that is to say, it received four units every half hour, or eight units in the hour, eighty units in ten hours, and eighty-four units in ten hours and a-half. Thus he discovered that it took eighty-four units of heat to change a pound weight of ice at 0° C. into water at 4° C. Of this immense quantity of heat only four units are accounted for by the thermometer. Eighty units have disappeared, and are represented simply by the fact that the ice has been melted.

This result was subsequently confirmed by another method of experiment, also due to Dr. Black, and not less ingenious than the former. It is called the method of mixtures. If I take a pound weight of water at 100° C., that is of boiling water, and mix it with a pound weight of water at 0° C., I get two pounds weight of water at about 50° C. This is what we should naturally expect. The pound of boiling water, in falling from 100° C. to 50° C., gives up fifty units of heat; and the pound of ice-cold water, receiving these fifty units of heat, is raised from 0° C. to 50° C. But if I pour a pound of water at 100° C. upon a pound of broken ice at 0° C., and stir them up together until the ice is all melted,

the thermometer will show the temperature of the mixture to be somewhere about 10° C. Let us try and interpret the meaning of this fact. The pound weight of boiling water, in falling from 100° C. to 10° C., gives up ninety units of heat; and the pound weight of ice, receiving these ninety units, is melted, and raised from 0° C. to 10° C. Thus it appears that of the ninety units given up by the hot water only ten units are accounted for by the thermometer, and eighty units are missing.

The heat that disappears, in this way, when ice is melted was called by Dr. Black Latent Heat, and the name is still preserved. But his researches did not end here. Having satisfied himself that eighty units of heat disappear whenever a pound weight of ice is converted into water, he asked the further question, What would happen if the water were converted back again into ice? Would the missing heat reappear? He tried the experiment, and he found that the missing heat did re-appear. Whenever a pound weight of water at 0° C. is converted into ice, eighty units of heat are developed, and generally given up to the surrounding bodies.

Here, then, are two fundamental facts that call for explanation. When a pound weight of ice at 0° C. is converted into water at the same temperature, eighty units of heat are absorbed; and when a pound weight of water at 0° C. is converted into ice at the same temperature, eighty units of heat are developed. We cannot forbear asking, Where does the heat go to that disappears when the ice is melted, and where does the heat come from that appears again when the water is frozen? Let us take

our two theories of heat, and see what answer they can give to these questions.

The Two Theories Compared. — According to the old theory, the heat that is poured into the melting ice is a kind of matter, a subtle and elastic fluid; and the advocates of the theory used to suppose that water has a great capacity for holding this fluid. Between the molecules of the water, they said, there are minute spaces, into which the heat finds its way, and there lies hidden as long as the water remains in the liquid state. In this condition the heat produces no sensible effect on a thermometer. But no sooner does the water begin to pass back into the solid form of ice than this heat is forced to come out from its lurking place, and to make itself sensible once again. This was the doctrine of Latent Heat that prevailed from the time of Dr. Black down to nearly the close of the last century.

But, according to the modern theory, when we add heat to a mass of melting ice, we do not pour into it a certain quantity of matter, but we impart to it a certain amount of energy. This energy goes to pull asunder the molecules of the ice, against the action of the molecular forces that tend to keep them locked together in the solid form. In overcoming these forces the energy expends itself, and ceases to exist as heat.

Let me try to bring home this conception clearly to your minds. You see these two blocks of lead suspended by separate strings from the same point of the iron ring of a retort stand. Under the influence of gravity each tends to place itself vertically below the point of suspension, and thus they cling together with a certain small force. If I

wish to pull them asunder I must overcome the force that is pulling them together, and in doing so I expend a certain definite amount of muscular energy. Now something of this kind must occur when ice is melted. There are certain molecular forces, the nature of which we do not exactly understand, but the existence of which is certain, that tend to keep the molecules of the ice in that mutual relation in which they constitute a solid body. To melt the ice it is necessary to overcome these molecular forces; heat is the agent by which this is done, and in doing it, heat expends a portion of its energy, just as I expend muscular energy in pulling asunder these two blocks of lead. In the one case millions upon millions of molecules are pulled asunder through indefinitely small spaces; in the other, two massive bodies are pulled asunder through a sensible distance; but in both cases a resisting force is overcome, and energy is expended in overcoming it.

Thus, according to the old theory, the heat that is poured into melting ice only hides itself in the interstices of the mass; while, according to the modern theory, it entirely expends itself in melting the ice, and ceases to exist as heat. But, you will ask, If the heat thus ceases to exist, how is it that the water gives up that heat again when it is converted back into ice? To answer this question I must take you back to a former illustration. You remember how the blow of a smith's hammer generates heat in an iron bar. The motion of the hammer, as a mass, is converted into a swinging motion of the molecules of the bar, and this swinging motion of the molecules is the objective physical fact that constitutes what we call the heat of the bar. Now

transfer this conception to the two blocks of lead suspended from the ring of our retort stand. When I pull them asunder, against the force of gravity, I expend a certain definite amount of energy. If I let them go, they fall together again, and, in falling, acquire an energy of motion exactly equal in amount to the energy that I had expended in pulling them asunder. But, at the moment of collision, this energy of motion ceases, and, like the energy of motion in the falling hammer, it is converted into the energy of heat. Now what takes place between these two masses, as they fall together, may be supposed to take place between the molecules of water, when they fall together into the solid state. In every minute drop of water there are millions of little molecules, held asunder in opposition to certain forces which tend to bring them together into the form of solid crystals. When the water begins to pass back to the solid state, the molecules begin to clash together under the action of these secret forces; and in the collision, heat is produced just as surely as when the smith's hammer strikes the iron bar. Thus heat is generated, by the collision of molecules, as crystal after crystal is built up, until, when the whole pound of water is converted back into ice, the eighty units of heat that were first expended in the process by which the ice was melted, have been again developed in the process by which the water is frozen.

The phenomenon of Latent Heat is not confined to water; it is exhibited by other liquids as well, under similar conditions. Whenever a solid is converted into a liquid, heat disappears in the process; and whenever a liquid is converted into a solid, heat is developed in the process.

The particular amount of heat required to melt a pound weight of any solid, already existing at its melting temperature, is called the Latent Heat of that liquid; because in the old theory, as I told you, it was supposed to lie hidden between the molecules of the liquid. It is remarkable how widely different is the Latent Heat of different liquids. We have seen that it takes about eighty units of heat to melt a pound weight of ice without raising its temperature; and hence the Latent Heat of water may be roughly set down at eighty. The most exact researches of recent times fix it at seventy-nine and a-quarter. There is no other substance that requires so much heat, simply to melt it, as ice does. Thus, for example, if nitrate of soda has been already heated to its melting point, only sixty-three units of heat are required to melt a pound weight of it; nitrate of potash requires only forty-seven units; silver, twenty-one; lead, five and a-half; and mercury, less than three.

Freezing Mixtures.—A solid may be changed into a liquid not only by melting it, but also by dissolving it; as salt, for instance, is dissolved in water, or as sugar is dissolved in tea. Since the particles of the solid body must be torn asunder against resisting forces, in the one case as in the other, we should naturally expect that heat must be expended when a solid is dissolved no less than when a solid is melted. That this is so, in fact, may be readily shown by experiment. Before you is a large beaker, half full of water, which is now at the temperature of the air in this hall; the thermometer shows it to be 12° C. And here, in this paper, is about half a pound of sal ammoniac, at the same temperature. I now plunge the bulb of a large air thermometer

into the water in the beaker, and fix it in its position by the arm of this retort stand. The long stem of the air thermometer is provided behind with a slip of white cardboard, so that everyone can see the coloured liquid in the stem. This coloured liquid will quickly reveal to you any change of temperature that may take place in the contents of the beaker. An increase of temperature makes the coloured liquid rise in the stem; a falling off in the temperature makes the coloured liquid fall. Now observe the effect produced, when I pour in the sal ammoniac, and stir it in the water. The sal ammoniac begins to dissolve, and the coloured liquid falls rapidly in the stem of the air thermometer. We were prepared for this result, and we are able to account for it. Heat must be expended to dissolve the solid body; and, as that heat is not furnished from without, it comes from the mixture itself, which is quickly chilled in consequence. With an ordinary mercurial thermometer I now try the temperature of the solution, and I find it has fallen to $-4°$ C., or four degrees Centigrade below freezing point.

This is the principle on which freezing mixtures are made. Two or more substances are mixed together, one of which, at least, is a solid, and is dissolved in the mixture. The heat that must be expended in dissolving the solid comes, in great part, from the mixture itself; and by the loss of this heat the mixture may be reduced to a temperature many degrees below freezing point. Here are two papers: one contains 600 grammes weight of sulphate of soda, a solid; the other, 500 grammes weight of nitrate of ammonia, a solid: and in this glass jar is contained dilute

nitric acid, weighing 400 grammes. All these substances are now at the temperature of this hall, 12° C. I mix them together in the glass jar; the two solids are rapidly dissolved in the nitric acid; and in a few moments, on inserting a thermometer, I find that the temperature has fallen to – 15° C., that is, 15 degrees Centigrade below freezing point.

If one of the substances, employed in the freezing mixture, is already at freezing point, the cold produced may become still more intense. One of the best freezing mixtures known is composed of snow and common salt, in the proportion of two parts, by weight, of snow to one of salt. In this case both the substances employed are solid, both are dissolved in the mixture, and one of them already exists at freezing temperature. In default of snow, pounded ice may be used as a substitute. While I have been speaking my assistant has mixed two pounds weight of broken ice with one pound of salt, and stirred them up together in this large glass beaker. I now introduce the thermometer into the mixture, and it falls at once to twenty degrees Centigrade below freezing point; and the thick fur of hoar frost, which will appear, in a few minutes, on the outside of the glass beaker, will be a sufficient evidence to all present that a very intense cold has been produced within.

Heat of Solidification.—These freezing mixtures furnish a striking proof that heat is expended when a solid is converted into a liquid. I will now give you one or two illustrations of the converse fact, that heat is developed when a liquid is changed into a solid. Here is a little apparatus in which the bulb and part of the stem of an ordinary thermometer

are surrounded by a small glass vessel, half filled with water. The glass vessel has been exhausted of its air, and hermetically sealed. Water, under these conditions, if kept in perfect repose, may be reduced to a temperature several degrees below freezing point, and still continue to exist in the liquid state. The molecules seem to be under some constraint, which prevents them from obeying the molecular forces that act upon them, and building up the solid crystals of ice. But a very slight disturbance is sufficient to release them from this constraint; the building up of the ice crystals then sets in with astonishing rapidity; and, in a moment or two, a great part of the liquid passes into the solid state. This fact is striking enough; but it will probably appear to you even more wonderful that, at the moment the water is converted into ice, it becomes sensibly warmer than it was before. The apparatus has been for some time standing in one of our freezing mixtures; and I find the Centigrade thermometer marks eight degrees below freezing point, the water still remaining liquid. I now shake the vessel; in an instant a portion of the water passes into ice, and the thermometer rises rapidly from $-8°$ C. to $0°$ C.

This experiment, though a very beautiful and interesting one, is unfortunately, from the nature of the case, not quite satisfactory to a large audience like the present. Only one person can see the actual rise of the thermometer at the moment the ice is formed; and, therefore, this fact, which is of cardinal importance, you are obliged to accept on the authority of my statement. But I will now show you an experiment, in which the evidence that heat is produced when a liquid is solidified, will be apparent to everyone

present in this hall. This glass beaker before you is filled, nearly to the top, with a clear transparent liquid; and resting in the liquid is an air thermometer, the stem of which, furnished behind with a slip of white cardboard, rises about twenty inches above the top of the beaker. Against the white background you can easily see a column of coloured liquid within the stem, which stands at present six or eight inches high. Every change of temperature in the contents of the beaker produces a movement in that column of coloured liquid: if you see the column rise in the stem, it is a proof that the contents of the beaker have got warmer; if you see the column fall, it is a proof that the contents of the beaker have got colder.

Now, the clear transparent liquid, contained in the beaker, has been obtained by dissolving a solid body, commonly called sulphate of soda, in water. It is found that hot water can dissolve a great deal more of this solid than cold water can. But if the solid be first dissolved in hot water, until the water can dissolve no more of it, and the solution be then allowed slowly to cool, being carefully protected, in the meantime, from dust and disturbance, it will still remain liquid, when cold. The solution before you has been prepared in this way. It was made, yesterday evening, at a temperature of about 40° C.; it was placed on this stand where you now see it; the thermometer was fixed in its place; and the surface of the solution was covered over with a layer of oil, to shut out the impurities of the atmosphere.

At the present moment, the solution would seem to be in a condition analogous to that of the water which we saw, a

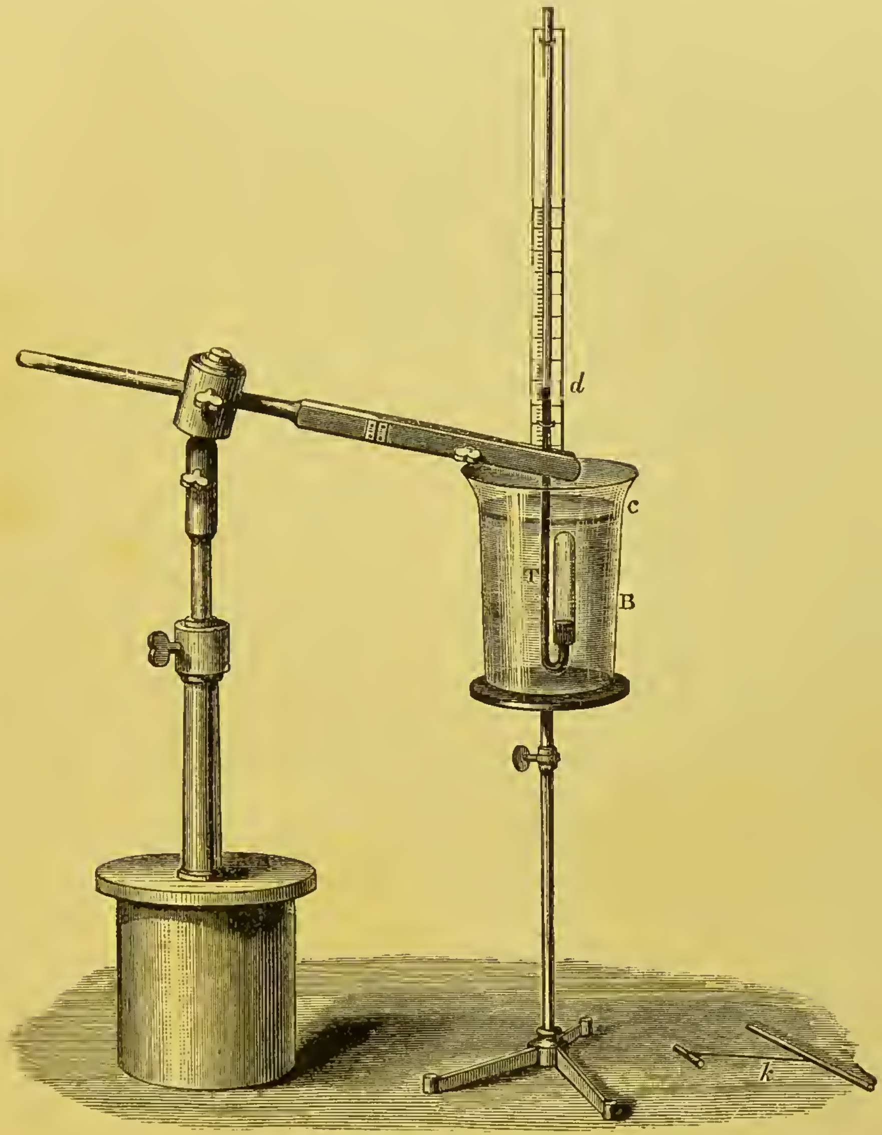

FIG. 2.

HEAT PRODUCED BY THE SOLIDIFICATION OF A LIQUID.

B Beaker holding Supersaturated Solution of Sulphate of Seda; Appearance before Solidification.
T Air Thermometer.
c Film of Oil on Surface of Solution.
d Height of Coloured Liquid in Stem of Thermometer, before Solidification.
k Copper Wire, with Crystal of Sulphate of Soda attache l.

few minutes ago, in the liquid state, at a temperature eight degrees below freezing point. The molecules of sulphate of soda are eagerly solicited by certain hidden forces to come together into the form of solid crystals. But they seem to be under some constraint, which makes it difficult for the process to begin. I can relieve them from this constraint by dropping into the liquid a small crystal of the same substance, which you see attached to this copper wire. The copper wire hangs down from the middle of a cross-piece, so that, when I drop in the crystal, the cross-piece rests on the upper edge of the beaker, and keeps the crystal suspended in the middle of the liquid mass. And now the building process has set in ; the molecules of sulphate of soda are rushing together in myriads ; and you can see the solid crystalline mass growing outwards, in all directions, with a rapidity that is certainly most wonderful. In the meantime, the coloured liquid is rising in the stem of the air thermometer, and, by its silent testimony, reveals to us that heat is generated as the sulphate of soda passes from the liquid to the solid state. The whole experiment has lasted not quite half a minute. In that time our clear transparent solution has become almost a solid mass; the coloured liquid has risen about four inches in the stem of the air thermometer; and a mercurial thermometer indicates that the contents of the beaker have been raised from 12° C. to 20° C.

Latent Heat in the Economy of Nature.—My last illustration of Latent Heat will be taken from those great natural phenomena that everyone can observe and study for himself. For it always seems to me a pleasant and a profitable practice, when we have been searching out,

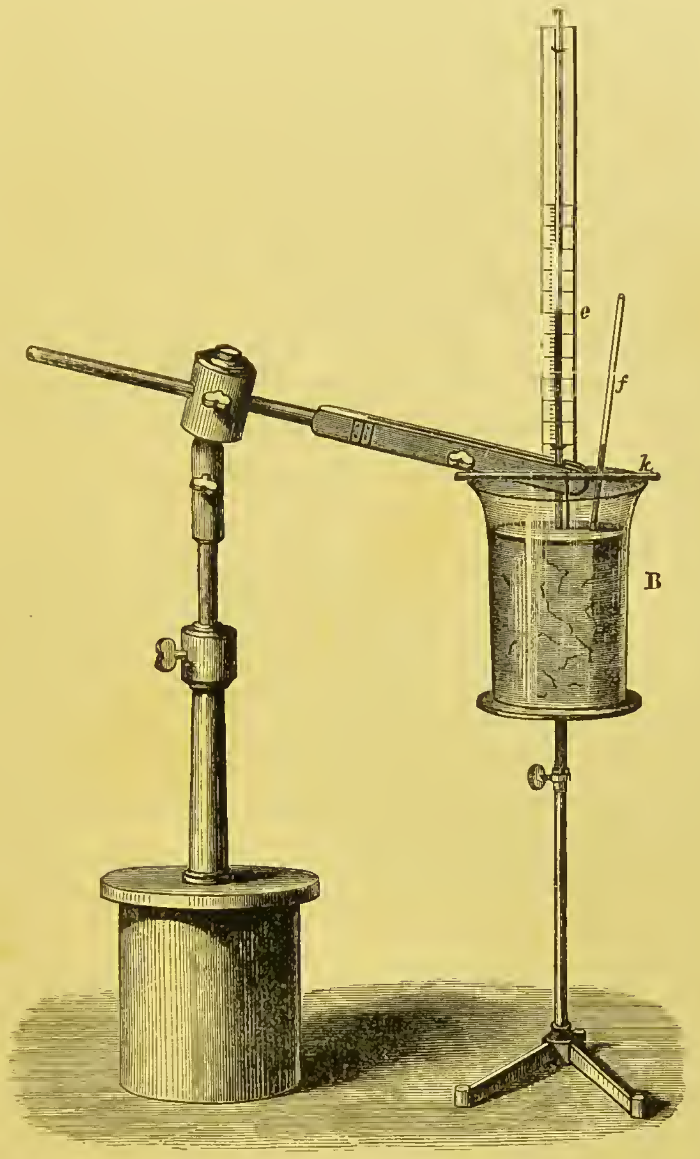

FIG. 3.

HEAT PRODUCED BY THE SOLIDIFICATION OF A LIQUID.

B. The same Beaker as in Fig. 2; Appearance after Solidification.
k Copper Wire, holding suspended a Crystal of Sulphate of Soda.
e Height of Coloured Liquid in Stem of Air Thermometer, after Solidification.
f Mercurial Thermometer.

to some extent, the laws that govern the material world, with the aid of such apparatus as human ingenuity has devised, to lift up our eyes, for a time, from the petty operations of the laboratory and the lecture hall, and turn them abroad on the face of Nature, where these same laws are presented to our view, on a scale of colossal magnitude. Everyone must have observed how long it takes, when a frost sets in, before a thick sheet of ice is formed on the surface of a lake. When the first crystal of ice appears, the surface has already been reduced to freezing point; and yet days often pass by, even during an unbroken frost, before the ice is one inch thick.

You will see, at once, that if this was only a question of temperature, the transition of a mass of water, at freezing point, to ice, would be almost instantaneous. But we have learned to-day that, for each pound of ice-cold water that passes into ice, eighty units of heat are given up, and must be carried off by the atmosphere; and this is plainly the reason why the process of freezing goes on so slowly. The quantity of heat, in fact, that must be taken away from water, at freezing point, in order to convert it into ice, would be sufficient, if it were added instead of being taken away, to raise the mass of water to within twenty degrees Centigrade of boiling point. Let me put this into figures for you. The lake at the Zoological Gardens is, I believe, about six acres in extent. Taking this estimate, and supposing the whole surface, to a depth of one inch, to have been already reduced to freezing point, you will find, from the data I have put before you to-day, that before it can be converted into ice, that layer of water must give up as

much heat as would be sufficient to boil somewhat more than 300 tons weight of ice-cold water.

Again, after a severe winter, great patches of snow may sometimes be seen, for a long time, hanging on the mountain slopes, holding their ground with wonderful pertinacity, as it would seem, against the increasing warmth of the spring. And many of you, no doubt, have seen how the great snow fields of the Alps are able to bid defiance, the whole summer through, to the consuming heat of a southern sun. The reason of all this is now made clear to us. For every pound weight of snow that is melted, eighty units of heat, at least, must be poured into the mass. Whether the balance, in the end, will be in favour of the snow-field or in favour of the sun, is simply a question of calculation. The quantity of snow that falls in the winter may be measured in pounds weight. The quantity of heat that is imparted to that snow, during the summer, may be measured in those Pound-Centigrade units that I have described to you. And if there be not, at least, eighty such units of heat, for every pound weight of snow that has fallen, then a balance of last season's snow will be carried over to the coming winter.

From these considerations it is evident that the Latent Heat of water has a very important influence in the economy of nature. It prevents those sudden changes which would be always inconvenient, and often destructive. If it were not for the Latent Heat of water, on the first approach of winter, when the temperature falls below freezing point, the rivers would be, at once, converted into massive blocks of ice, and would cease to flow in their channels. And when, with the changing seasons, the returning summer would

breathe again on the slopes and summits of the higher mountains, the snow fields would be melted in a day, and sweeping down with impetuous force, would flood the plains, and carry destruction in their course. But, through the influence of Latent Heat, the rivers are slowly frozen when winter comes, and the ice and snow are slowly melted, when winter passes away; thus affording evidence of the beneficent design that everywhere pervades the order of Nature, and guides all things for the use and convenience of man.

In conclusion, I beg to say, that I have brought before you to-day but one-half of my subject. I have dealt with the doctrine of Latent Heat in relation to liquids only. In my next lecture I propose to consider it in relation to vapours; a branch of the subject not less interesting than that which we have investigated to-day, and one which affords, perhaps, a larger scope for experimental illustration.

LECTURE II.

THE LATENT HEAT OF VAPOURS.

THE common domestic operation of boiling water is one with which you are all, no doubt, familiar, though perhaps you have not all observed it with the attention it deserves, or adverted to its full significance. It is an interesting and instructive operation under many different aspects; but I mean to refer to it to-day only in so far as it will help us to get a further insight into the laws of Latent Heat.

Heat Expended when Water is Boiled.—On the table before you is a flask, containing about a pound weight of water, which has been brought to boiling point by means of the gas-burner you see underneath it. Twenty minutes ago, the water was at the temperature of the air in this hall, which is 12° C.; but, as it received heat from the gas-burner, it got hotter and hotter, and the thermometer, which you see resting in it, rose higher and higher, until at last the water began to boil, and the thermometer then indicated 100° C. From that moment, though heat has been passing into the vessel, as before, the water has got no hotter, and the thermometer still stands at 100° C. And so matters would remain, if I left the gas burning under the flask,

until all the water had been boiled away, and diffused

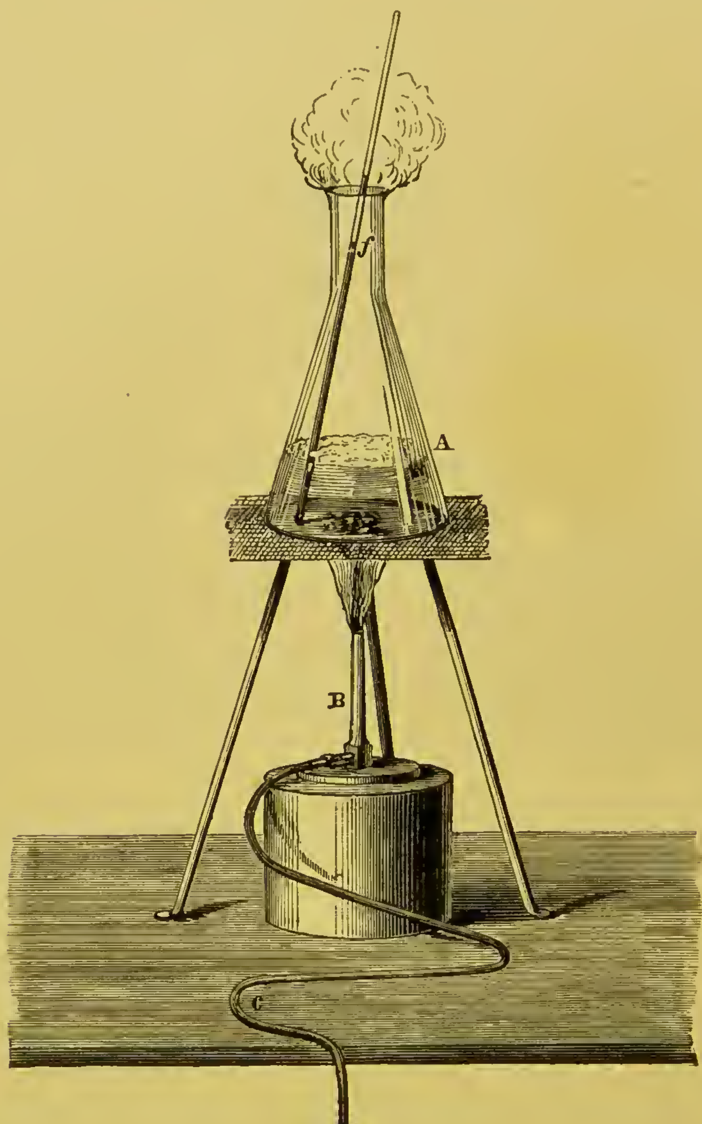

Fig. 4.

The Latent Heat of Steam.

A Flask of Boiling Water.
B Bunsen's Burner.
c Flexible Tube. coming from Gas-pipe.
f Thermometer, standing steadily at 100° C.

through the atmosphere in the form of vapour. Further, let it be observed, that when I lift up the thermometer,

and hold the bulb in the steam that passes off from the surface of the water, the mercury still stands 100° C.; showing that the temperature of the steam, into which the water has been converted, is no higher than that of the boiling water itself.

From the consideration of these facts the question naturally arises, What becomes of the heat that is thus poured into this boiling water, and that leaves the water no hotter than it was before? This question, you will see at once, is analogous to that which I discussed in my last lecture, with respect to the melting of ice; and we are naturally led to account for the heat that disappears when water is boiled, according to the same principles by which we account for the heat that disappears when ice is melted. Dr. Black, of Edinburgh, a hundred and twenty years ago, resting on the old theory, which regarded heat as a kind of matter, said that the missing heat lies concealed between the particles of the vapour into which the water has been converted; and that, when the vapour is changed back to water again, the heat is squeezed out from its hiding place, and forced to make itself sensible. But according to the modern theory, which regards heat as a kind of energy, all the heat that is added to boiling water is simply expended in doing work, that is, in converting the water from the state of a liquid to the state of a vapour.

Let us try to bring home clearly to our minds the nature of this work. Here is a large glass bulb with a long stem attached to it. The bulb has been filled with water, coloured with a crimson dye to make it more plainly visible, and this coloured water stands, as you see, at a

height of two or three inches in the stem. I now plunge the bulb, so prepared, into a large beaker of warm water. The water within the bulb soon becomes heated by the mass around it, and, at the same time, it expands in volume, for you see the coloured liquid is now slowly rising in the stem.

From this experiment we learn that, when water exists at a temperature below boiling point, the heat that is added to it produces two effects; it raises the temperature, and it increases the volume. The increase of temperature consists, according to the modern theory, in the increased energy with which the molecules swing about through indefinitely small spaces. The increase of volume is a consequence of this increased energy of vibration: for when the molecules are swinging about with greater energy than before, they naturally require more room to swing in; they get farther away from one another, and so they come, in the aggregate, to occupy a greater space. But this second effect, though a consequence of the first, implies, in itself, a two-fold work, which cannot be done without a corresponding expenditure of energy. First, the particles of water have to be pulled asunder against the resistance of those molecular forces which tend to keep them locked together; and secondly, as the water expands, it must, of necessity, push back the atmosphere before it, which is practically equivalent to lifting a weight of fifteen pounds on every square inch of surface.

Thus, when the water within this bulb is heated, a portion of the heat imparted to it goes to make it hotter, and a portion goes to do the work I have described. The portion that goes to make it hotter continues to exist as heat; the

portion that goes to do the work ceases to exist as heat, and is represented, in fact, by so much work done. But when the boiling point is reached, the water, supposing it always to exist in an open vessel, is incapable of being raised to a higher temperature. Instead of getting hotter, it now begins to pass rapidly into the form of vapour, in which its volume, which before had been increasing by slow degrees, is now increased, at once, seventeen hundred-fold. From this moment, then, all the heat that is poured into the mass is expended in doing the two-fold work I have described; that is, in pulling asunder the molecules against the forces that tend to keep them locked together, and in pushing back the weight of the atmosphere.

The heat that is thus expended in converting a pound weight of water, at boiling point, into vapour, or steam, at the same temperature, is called the Latent Heat of the vapour; and we have now to consider how much heat is required to produce this change. As before, we will take, for our unit of measurement, the quantity of heat that is necessary to raise a pound weight of water through one degree of the Centigrade scale; and we will call it a Pound-Centigrade unit of heat. The problem before us is to determine how many such units of heat must be added to a pound weight of boiling water, before the whole of the water will have been converted into vapour.

Here is a very simple experiment, which everyone can repeat for himself, without any expensive apparatus, and which is amply sufficient for a rough approximation. Yesterday I took a pound weight of water and put it into that flask before you: the temperature of the water

at the time was 20° C. I then put this spirit-lamp under the flask, and, marking the time, I found that in half an hour the water began to boil. This observation gave me a rough measure of the quantity of heat that passed, in half an hour, from the spirit-lamp into the flask; for, to raise a pound weight of water from 20° C. to 100° C., requires just 80 Pound-Centigrade units of heat. Leaving the flask of boiling water and the spirit-lamp in the same relative positions, I now waited until all the water was boiled away, and I found that this process took just three hours and a-half. Now, since 80 units of heat passed from the spirit-lamp into the flask, in each half hour, it follows that 80 units multiplied by 7, or 560 units, must have passed in three hours and a-half: and, consequently, this enormous quantity of heat, according to the experiment, must be added to a pound weight of boiling water, in order to convert it into steam at the same temperature.

You will easily understand that an experiment such as this can only give a rough approximation to the truth; and, I need hardly say, that the elaborate methods of investigation which are necessary for exact measurement are unsuited to an occasion like the present. It is interesting however to know that, according to the most careful researches, recently made, in which every source of error has been, as far as possible, excluded or allowed for, the Latent Heat of the vapour of water, at 100° C., is 537; that is to say, it takes 537 Pound-Centigrade units of heat to convert a pound weight of boiling water into vapour.

Heat Given out when Steam is Condensed.—We saw, in the last lecture, that when a liquid is converted into a solid,

as much heat is given out, and made sensible, as would be expended in converting the solid back again into a liquid; and I explained, at some length, how this fact is accounted for in the modern theory of heat. We find a phenomenon exactly analogous to this in the case of a vapour and a liquid. Five hundred and thirty-seven units of heat must be expended to convert a pound of boiling water into steam at the same temperature; and when the steam is converted back into water, 537 units of heat will be again made sensible. This may be roughly shown by an experiment which would be much too tedious to perform here, but which I may be allowed briefly to explain.

Suppose I put a pound weight of water, at 0° C., into this glass beaker, and then, surrounding the vessel with a good non-conducting material, allow the steam from a flask of boiling water to pass into it by means of a bent glass tube, the steam, as it passes in, will be condensed into the liquid state, and the heat it gives up will be imparted to the pound of cold water. At the end of some time the water will begin to boil: it will then have received just 100 units of heat from the condensation of the steam. To appreciate this experiment fully you must observe that the steam itself, which came into the vessel at 100° C., now exists there as water, at the same temperature; it is therefore neither hotter nor colder than it was before. We are consequently justified in concluding that the hundred units of heat which the pound weight of water has received have all been developed by the simple liquefaction of the steam. If we now weigh the water in the flask we shall find that it has been increased during the experiment, to an amount equal to about the fifth

of a pound. That is to say, a quantity of steam, weighing about the fifth of a pound, has given up 100 units of heat in passing into the liquid state. From this experiment, then, we might infer roughly that a pound weight of steam would generate, by its liquefaction, 500 units of heat. If the

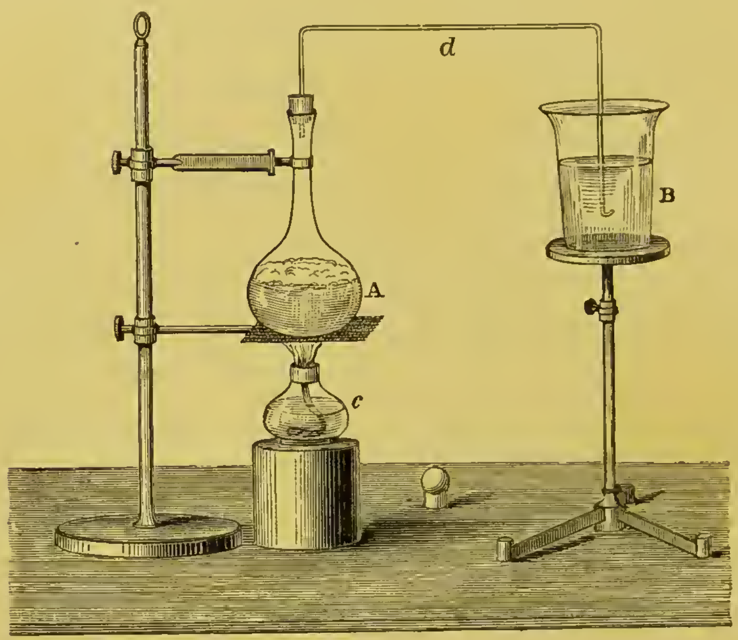

Fig. 5.

Heat Developed by the Condensation of Vapour.

A Flask of Boiling Water.
B Beaker of Cold Water.
c Spirit Lamp.

d Bent Glass Tube, passing through Cork of Flask, and dipping under the Surface of the Water in Beaker.

experiment were made with great care, and freed from all sources of error, the exact number would be 537.

This experiment, I may say in passing, enables us at once to understand the system of heating buildings by steam, which has recently been introduced into this city.

The steam acts simply as a carrier of heat, which it receives in the boiler, and distributes over the building; and you see, from the considerations I have set before you, what an efficient carrier it is. Suppose a pound weight of steam, at 100° C., goes forth from the boiler, and after having carried heat to all parts of the house, returns to the boiler in the form of water at 30° C., that pound of steam has distributed through the building, in the first place, 537 units of heat, which it gave up in passing back to the liquid state, and then 70 units more, which it lost in falling from 100° C. to 30° C., making in all 607 units of heat. Whereas if a pound of hot water goes out from the boiler, at 100° C., and comes back at 30° C., it gives up, in its passage through the building, only 70 units of heat in all. Observe I do not mean to pronounce any opinion upon the comparative merits of the two systems of heating. That is a much larger question, and it involves considerations outside of our present subject. I only mean to say that, considered merely as a carrier of heat, steam is far more efficient than hot water, and for this simple reason, that it can carry a great deal more.

Heat Expended in Evaporation.—When water is boiling, it is converted into vapour with great rapidity: bubbles of steam are formed within the mass of the liquid itself, force their way to the surface, and escape into the air with a certain explosive force. But water may be converted into vapour at lower temperatures, though much less rapidly, and only at the free surface where the water is in contact with the air. In this case the process is usually known under the name of evaporation. Whenever water is exposed to the air, evaporation goes on more or less rapidly; and the point

I want to insist on just now is this, that the conversion of water into vapour, by the slow process of evaporation, is due to the expenditure of heat, just as truly as when it is effected by the more rapid process of boiling. Nay more: the amount of heat that must be expended to convert a given weight of water into vapour increases as the temperature gets lower. We have seen that the Latent Heat of the vapour of water, at 100° C., is 537. At 12° C., which is about the temperature of this hall, it is 600; that is to say, it takes 600 units of heat to convert a pound weight of water, at 12° C., into vapour at the same temperature.

All other liquids—alcohol, for example, ether, bisulphide of carbon—may, like water, be converted into vapour; and the quantity of heat required to convert a given weight of the liquid, at its own boiling point, into vapour, at the same temperature, is called, in each case, the Latent Heat of that particular vapour. Thus the Latent Heat of the vapour of alcohol is 200; the Latent Heat of the vapour of ether is 90. It is worth remembering that water holds a very remarkable position with regard to this phenomenon of Latent Heat. The Latent Heat of water, in the liquid state, is greater than that of any other liquid; and the Latent Heat of water, in the state of vapour, is greater than that of any other vapour. In other words, it takes more heat to convert a pound of melting ice into water than to convert a pound of any other solid, already existing at its melting temperature, into its corresponding liquid; and it takes more heat to convert a pound of boiling water into vapour than to convert a pound of any other liquid, already boiling, into its corresponding vapour.

Practical Illustrations.—Let me now give you some practical illustrations of the Latent Heat of vapours. It is a familiar fact that if you get a wetting, and remain in wet clothes, you soon begin to feel intensely cold; but perhaps the reason of this fact is not quite so familiar. It is not the coldness of the water that produces this effect, for the water is no colder than the surrounding air: it is the evaporation of the water, a process that goes on very rapidly, as the water is spread over a large surface. This evaporation, as we have seen, is effected by the expenditure of heat; and the greater part of the heat required is taken from your body, which may be regarded as a storehouse of heat, ready at hand for the purpose. It may be roughly stated that, for every drop of water converted into vapour, you expend of your own heat as much as would raise 500 drops through one degree Centigrade, or, say, 5 drops through 100 degrees Centigrade, that is, from freezing to boiling point. Nor will you mend matters much by standing near a fire, because the heat of the fire only tends to make the evaporation more rapid; and, as it expends itself in doing so, it fails to make you warm.

I may illustrate these considerations by a very simple experiment. On the table before you, supported by a retort stand, is a large air thermometer, the bulb of which is covered with a muslin bag. In the stem of the thermometer you see a coloured liquid, which stands out in relief against the slip of white cardboard behind it. This coloured liquid rises in the stem when the air in the bulb expands, and falls in the stem when the air in the bulb contracts; and since the air expands with heat and contracts with cold, the movement of

the coloured liquid will indicate to us any change of temperature that takes place within the bulb. Taking a small

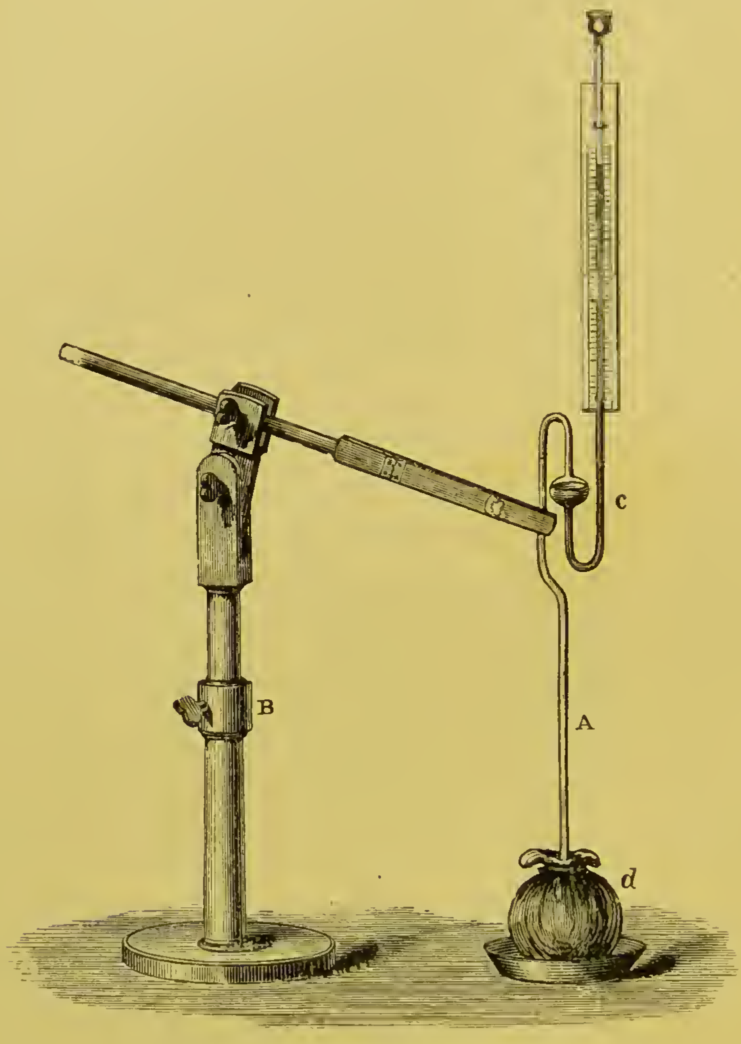

FIG. 6.

HEAT EXPENDED IN THE PROCESS OF EVAPORATION.

A Large Air Thermometer.
B Retort Stand.
c Coloured Liquid in Stem.
d Muslin Bag, covering Bulb of Thermometer.

beaker of water, at the same temperature as the surrounding air, I pour out a thin stream over the muslin bag. The bulb

of the thermometer is now practically sitting in wet clothes, and you can see for yourselves the effect produced. The water begins to evaporate; the process of evaporation involves the expenditure of the heat; the heat is furnished, in great part, by the bulb itself and the air within it; the air losing its heat contracts; and now the coloured liquid, falling in the stem, plainly reveals to the eye the chilling effect produced by the evaporation. I place a jet of burning gas within a few inches of the bulb, but the coloured liquid remains stationary at the point to which it had fallen. The heat that comes from the flame hastens the process of evaporation, but has no sensible effect in heating the air within the bulb.

Sulphuric ether is a liquid much more volatile than water, that is, much more rapidly converted into vapour at ordinary temperatures, and, consequently, its evaporation causes a more intense cold. The bottle that I hold in my hand is filled with sulphuric ether; and by means of this ingenious apparatus attached to the bottle, which I dare say is familiar to most of you, I now scatter a fine ether spray over the bulb of the thermometer, already chilled by the evaporation of water. You see how quickly the coloured liquid in the stem responds to my action, and by its rapid descent reveals to us the sudden expenditure of heat involved in the evaporation of the ether. When sulphuric ether is scattered, in the form of a fine spray, on the surface of the human body, the cold produced is so intense as to cause temporary insensibility where the spray falls. Hence it is employed not unfrequently by surgeons, when painful operations have to be performed.

Water Frozen by Evaporation.—Ether has been used also, with some success, as an agent for the artificial production of ice. Here is a narrow glass vessel, within which is suspended a test tube. The glass vessel is nearly full of ether, and the

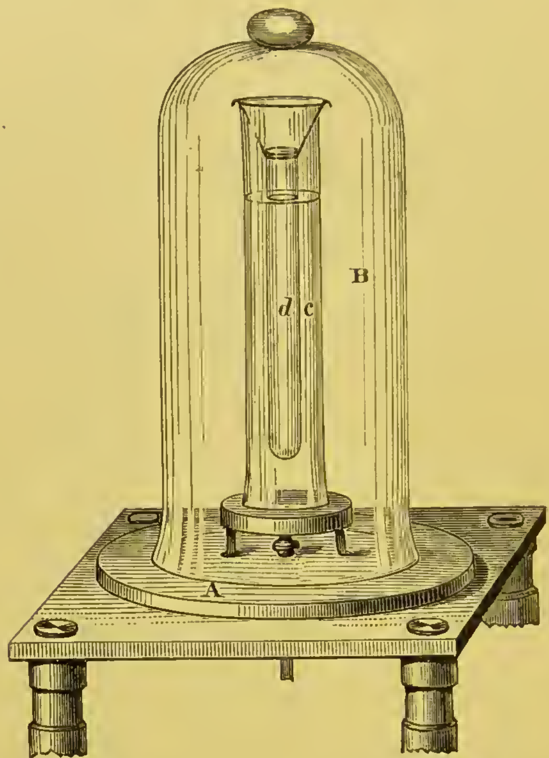

Fig. 7.

Water Frozen by Evaporation of Ether.

A Plate of Air Pump.
B Receiver, fitting air-tight on A.
c Tall Glass Jar, nearly full of Ether.
d Test Tube, nearly full of Water, and immersed in the Ether.

test tube of water. I place them both, thus prepared, on the plate of an air pump, and cover them with a glass receiver. My assistant will now proceed to exhaust the air. As the pressure is removed from the surface of the ether, the process of evaporation is greatly accelerated, and now you can see

the ether boiling violently in the partial vacuum that has been created. This rapid evaporation implies the rapid expenditure of heat, which must come, of course, from the ether itself, from the test tube that is plunged in it, and from the water within the test tube. Hence a rapid fall in the temperature of the water, which now begins to freeze. At the end of four minutes I remove the receiver, and take out the test tube: you see that the water has been converted into a solid block of ice.

Leslie's Experiment.—In the experiment I have just shown you water is frozen by the evaporation of ether. About the beginning of the present century, Sir John Leslie, then Professor of Mathematics in the University of Edinburgh, conceived the idea of freezing water by its own evaporation. You all know, I dare say, that the temperature at which water boils, depends on the pressure under which it exists. At the ordinary pressure of the atmosphere, water boils at 100° C.; but when the pressure is reduced, it will boil at a much lower temperature. On the top of Mont Blanc, for example, the pressure is not quite three-fifths of what it is at the sea-level, and water boils at 85° C. At Quito, in South America, which is 9,500 feet above the sea-level, the pressure of the atmosphere is little more than two-thirds of what it is with us here, in Dublin; and water boils there at about 90° C. I have been told by a person who travelled in that country, that he found it impossible to boil potatoes at Quito; and he thought there must have been something wrong with the potatoes. But the true explanation would seem to be furnished by the fact we are now considering. Water placed in an open vessel, that is, a vessel from which the steam has

free escape, at the altitude of Quito, begins to boil at 90° C. After this point has been reached the water can get no hotter; for all the heat that is added is expended in converting the water into steam: and it would seem, from the experience of my friend, that this temperature is not sufficiently high for the proper cooking of potatoes.

Under the receiver of an air-pump, the pressure can be reduced very readily to the one-sixtieth part of an atmosphere; and at such a pressure water will boil at a very low temperature indeed. Now, even in these conditions the conversion of water into vapour is still effected by the expenditure of heat; and as that heat must be taken from the bodies that are nearest at hand, it is taken in great part from the water itself. Hence water placed in an air-pump vacuum must be quickly chilled, owing to the loss of heat, due to the very rapid evaporation that takes place under the diminished pressure.

But the process of evaporation would, under ordinary circumstances, cease altogether after a few minutes; because the space within the receiver would become fully charged, or, as it is usually expressed, saturated with vapour, and could receive no more. To meet this difficulty, Sir John Leslie placed on the plate of an air-pump a shallow vessel filled with sulphuric acid, which has an extraordinary power of absorbing the vapour of water. By this means he succeeded in clearing away the vapour as fast as it was produced, and so, keeping up a good vacuum with the air-pump, he was able to continue the process of rapid evaporation until the water fell below freezing point, and then gradually passed into ice.

Carré's Apparatus.—This experiment was successfully performed, for the first time, before the Royal Society, in the year 1810. It may be shown on a larger scale, and with greater facility, by means of the apparatus before you, which

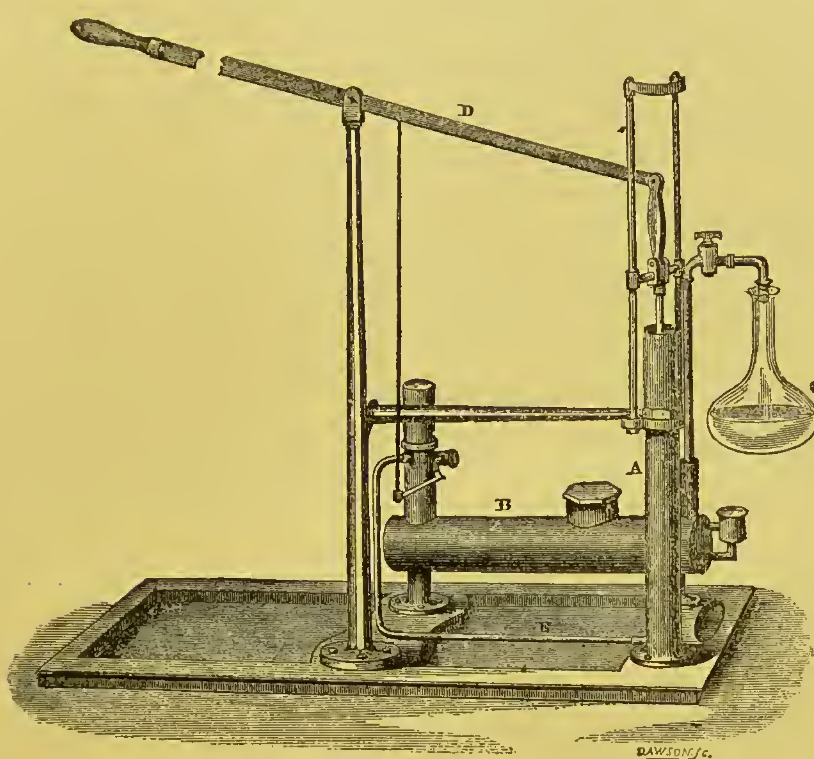

FIG. 8.

CARRÉ'S MACHINE FOR FREEZING WATER BY ITS OWN EVAPORATION.

A Barrel of Air-Pump.
B Leaden Chamber, containing Sulphuric Acid.
C Flask of Water, attached to Brass Nozzle, and communicationg with Leaden Chamber.
D Lever to work Piston of Air-Pump.
E Copper Tube through which the Air is withdrawn.

has been invented and constructed by the ingenious M. Carré, of Paris. This apparatus consists essentially of an air-pump, with which is connected a leaden chamber half filled with sulphuric acid. The leaden chamber communicates with a

brass nozzle, to which I now attach, by an air-tight joint, a flask containing water at the temperature of this hall, 12° C.

When the pump is worked, by means of this long lever, the first effect is to produce a partial vacuum in the flask. The process of evaporation goes on more rapidly under the diminished pressure, and the temperature of the water falls. Meanwhile, as the air and the vapour continue to be drawn away from the flask, by the action of the pump, they pass over the surface of the sulphuric acid in the leaden chamber; the vapour is absorbed rapidly by the sulphuric acid, and the air is expelled through the barrel of the pump. After thirty or forty strokes the water begins to boil; and here we have a phenomenon which is, at the same time, very striking and very instructive. We are accustomed to associate the idea of boiling water with hot water; because we commonly see water boiling under the pressure of the atmosphere; and under that pressure, it will not boil, unless it is hot. But, in the experiment now before us, we have removed this pressure, and the water begins to boil while it is actually falling from 12° C. to freezing point. Nay more, it is the very process of boiling that makes the water colder. For here there is no fire to furnish the heat that must be expended in boiling the water; that heat must come from the water itself; and the water gets cold, simply because the heat that before kept it warm is now expended in changing it into vapour.

And now we have at last reached freezing point. By the aid of a beam of light, which my assistant has projected from the oxy-hydrogen lamp, you can all see, I trust, that

little group of ice crystals that has suddenly sprung into existence on the surface of the water. It is growing rapidly in all directions; and even while I speak it has developed into a thin sheet of ice, which will now get gradually thicker until it becomes a solid block. But what has become, meanwhile, of the heat that has been taken away from the water within this flask? The answer to this question may be easily deduced from the principles already established. In the first place, it ceased to exist as heat because it was expended in converting the water into vapour. But, then, this vapour having been absorbed by the sulphuric acid, and thus brought back to the liquid state, the heat that was expended before again re-appears. In proof of this, I need only put my hand on the surface of the leaden chamber, and I can feel that it has got sensibly hot while the water was getting cold. A portion of this heat is, no doubt, produced by the chemical action of the sulphuric acid on the water, but the greater part is due simply to the condensation of the vapour.

Carbonic Acid Snow.—One experiment yet remains, which exhibits, in a very interesting way, the Latent Heat of vapours. Carbonic acid, as I dare say you know, commonly exists in the form of a gas. It has a large share in the functions of animal and vegetable life, and is familiar to us in the phenomena of every-day experience. When we breathe, we take into our lungs the oxygen of the atmosphere, and we send forth carbonic acid; whereas plants and trees take in carbonic acid, and send forth oxygen. Every candle flame and gas flame, and every fire, whether of coal or turf or wood, is maintained by the combustion of carbon,

and earbonie aeid is one of the products of combustion. It is known to us also as the gas that sparkles so brightly in soda-water and in champagne. Now this gas ean be redueed to a liquid state under the influence of great pressure, or of great eold, or of both. A quantity of it which, under ordinary pressure, would oeeupy a volume of about 200 gallons, existing as a gas, has been eondensed, in this iron bottle, into about a pint of liquid. It exists here, at present, under a pressure of five or six hundred pounds to the square ineh. But when the screw is turned, whieh closes the neck of the iron bottle, the liquid is put at onee into eommunieation with the air; the pressure of five or six hundred pounds is changed into a pressure of fifteen pounds, to the square inch; and the liquid suddenly flashes out into vapour. This ehange involves, as we have seen, the expenditure of heat, and the eold produeed, in consequenee, is so intense that the earbonie acid, whieh eomes forth as a vapour, is quickly frozen into a solid, and falls down in the form of snow.

My assistant will now turn the serew, and allow the vapour to eseape. See with what foree it streams through the air; and observe those white particles of solid matter floating in the stream and marking its path. These are minute seraps of carbonie acid snow. I may eollect them, as they form, by attaehing this brass box to the nozzle of the iron bottle. The jet of vapour now plays against the sides of the box; the seraps of snow are gathered together, and in a few moments I have quite a large mass of it aeeumulated. It is not unlike ordinary snow in appearanee, but it is very much eolder than any snow ever seen in these latitudes. The temperature has not been exaetly determined, but it is

estimated at from eighty to ninety degrees Centigrade below the freezing point of water. You may take it lightly in your hand without suffering any inconvenience; but if you press it between your fingers, it will blister you like a hot iron.

This carbonic acid snow may be made still colder by pouring ether on it, for the ether dissolves the solid, and heat is given up in the process. In fact, solid carbonic acid and ether combined constitute a powerful freezing mixture, on the principles already explained. In this mixture a large quantity of mercury can be frozen, though its freezing point is about forty degrees below zero Centigrade. Let us make the experiment. I put this snow ball of solid carbonic acid into a porcelain saucer, having first taken care to protect the saucer from the intense cold, by interposing a leaf of paper; next, I add a small quantity of ether to the solid mass, and then into the mixture I pour a couple of pounds weight of mercury. It is frozen at once, and I can lift it up in a solid block, by means of this little tray of wire gauze, previously laid on the paper in the porcelain saucer, to receive the mercury, and now firmly frozen into it. I transfer the whole mass into this tall glass vessel full of water; the mercury soon begins to melt, and passing through the meshes of the wire gauze, falls down in liquid jets through the water. But observe what a curious phenomenon is presented to us, and made visible, as I hope, to all, by the beam of the oxy-hydrogen lamp, which is now projected by my assistant on the tall glass vessel. The falling mercury, though in a liquid state, is still many degrees below the freezing point of water; and so, each jet of mercury, as it falls, freezes the water around it, and you can see near

the surface a number of little funnels of ice, through which the liquid mercury streams down to the bottom of the vessel.

The Latent Heat of vapours plays an important part in the great operations of Nature, and, before coming to an end, I should like to give you one remarkable illustration of its influence. We have seen that steam, or the vapour of water, is a very efficient agent as a carrier of heat; and that, in this capacity, it is now used to distribute through our private dwellings and our public buildings the heat that is generated in a central furnace. Now, it is a very interesting fact, that a process of essentially the same kind has been employed, for countless ages, to distribute over our globe the heat that is poured down into the waters of the torrid zone, from the great furnace of the sun. This heat is largely expended in converting water into vapour. The vapour, rising up into the atmosphere, is borne, by the Trade Winds, north and south; as it passes into the colder regions of the temperate zones, it is again condensed into the liquid state, and appears in the form of minute particles of water, which gathering together in large masses, float as clouds over our heads, and then, blending into drops, fall down as rain to the ground. For every pound weight of water that is thus produced, about 600 units of heat are given up to our atmosphere; and thus, through the unseen, and almost unnoticed, action of the principles we have been considering to-day, this universal element of water, so wonderful in all its various aspects, is turned to account by Nature, to temper the inclemency of our northern climate with the heat it has carried off from the distant storehouse of the tropics.

Summary.—And now, in conclusion, let me sum up briefly the doctrine of Latent Heat, as I have tried to set it before you in these two lectures. When heat is given to a body and makes it hotter, it is called Sensible Heat: when it is given to a body and does not make it hotter, it is called Latent Heat. The name of Latent Heat was founded originally on a wrong conception. Heat was considered to be a kind of matter, and when this matter was poured into a body, and did not make it hotter, it was supposed to lie hidden, somehow, between the molecules of the body, and so it was said to be Latent. But now we know that heat is a kind of energy, and that, like other kinds of energy, it is capable of doing work. When it is imparted to a body it may stir up its molecules, so as to make them swing about with a more intense activity than before: in this case it makes the body hotter. But it may do other kinds of work; such as pulling asunder the particles of the body, against the molecular forces that tend to keep them locked together, or pushing back the pressure of the atmosphere, which resists the expansion of the body; and in so far as it is thus expended, it does not make the body hotter, and ceases, in fact, to exist as heat.

Hence, according to the modern theory, when heat is imparted to a body, we must conceive, under the name of Sensible Heat, that portion which goes to intensify the vibration of its molecules, and consequently to make it hotter; while under the name of Latent Heat, we must conceive that portion which goes to do other work such as I have described, and to produce thereby some change in the constitution of the body. The heat that is called Sensible

continues still to exist as heat; the heat that is called Latent ceases to exist as heat. In certain conditions of a body, *all* the heat that is given to it goes to produce a change in its constitution, and no part goes to make it hotter. This occurs when it is passing from the solid to the liquid state, or from the liquid state to the state of vapour. In these circumstances, therefore, the phenomenon of Latent Heat is brought before us in its most simple and striking form; and, consequently, these changes in the condition of matter are usually selected for the purpose of investigating and illustrating the laws that govern the phenomenon.

Lastly, it is important to remember that, whenever a vapour is converted back into a liquid, or a liquid into a solid, the molecules of the body, which had been pulled asunder by the expenditure of heat, clash together again, and, by the force of the collision, generate just the same amount of heat that had been expended in pulling them asunder. Hence the name of Latent Heat, which in the first instance was founded on an error, is not altogether inappropriate, and may well be retained for want of a better. It is true that the heat so called has, in reality, ceased to exist as heat; but it has imparted to the body, in which it was formerly supposed to lie concealed, a capacity for producing an equal amount of heat at some future time.

LIGHTNING, THUNDER,

AND

LIGHTNING CONDUCTORS.

TWO LECTURES

DELIVERED IN THE THEATRE OF THE ROYAL DUBLIN SOCIETY,

APRIL, 1881.

LECTURE I.

LIGHTNING AND THUNDER.

LECTURE II.

LIGHTNING CONDUCTORS.

LECTURE I.

LIGHTNING AND THUNDER.

THE electricity produced by an ordinary electric machine exhibits, under certain conditions, phenomena which bear a striking resemblance to the phenomena attendant on Lightning. In both cases there is a flash of light; in both there is a report, which, in the case of Lightning, we call Thunder; and, in both cases, intense heat is developed, which is capable of setting fire to combustible bodies. Further, the spark from an electric machine travels through space with extraordinary rapidity, and so does a flash of Lightning; the spark follows a zig-zag course, and so does a flash of Lightning; the spark moves silently and harmlessly through metal rods and stout wires, while it forces its way, with destructive effect, through bad conductors, and it is so, too, with a flash of Lightning. Lastly, the electricity of a machine is capable of giving a severe shock to the human body; and we know that Lightning gives a shock so severe as usually to cause immediate death. For these reasons, it was long conjectured by scientific men that Lightning is, in its nature, identical with electricity; and that it differs from the electricity of our machines only in this, that it exists in a more powerful and destructive form.

Identity of Lightning and Electricity.—But it was reserved for the celebrated Benjamin Franklin to demonstrate the truth of this conjecture by direct experiment. He first conceived the idea of drawing electricity from a Thundercloud, in the same way as it is drawn from the conductor of an electric machine. For this purpose, he proposed to place a kind of sentry-box on the summit of a lofty tower, and to erect, on the sentry-box, a metal rod, projecting twenty or thirty feet upwards into the air, pointed at the end, and having no electrical communication with the earth. He predicted that, when a Thundercloud would pass over the tower, the metal rod would become charged with electricity, and that an observer, stationed in the sentry-box, might draw from it, at pleasure, a succession of electric sparks.

With the magnanimity of a really great man, Franklin published this project to the world; being more solicitous to extend the domain of science by new discoveries, than to secure for himself the glory of having made them. The project was set forth in a letter to Mr. Collinson of London, which bears date July 29, 1750, and which, in the course of a year or two, was translated into the principal languages of Europe. Two years later, the experiment suggested by Franklin was made by Monsieur Dalibard, a wealthy man of science, at his villa near Marly-la-Ville, a few miles from Paris. In the middle of an elevated plain Monsieur Dalibard erected an iron rod, forty feet in length, one inch in diameter, and ending above in a sharp steel point: the iron rod rested on an insulating support, and was kept in position by means of silk cords.

In the absence of Monsieur Dalibard, who was called by

business to Paris, this apparatus was watched by an old dragoon, named Coiffier; and on the afternoon of the tenth of May, 1752, he drew sparks from the lower end of the rod, at the time that a Thundercloud was passing over the neighbourhood. Conscious of the importance that would be attached to this phenomenon, the old dragoon summoned, in all haste, the prior of Marly to come and witness it. The prior came without delay, and he was followed by some of the principal inhabitants of the village. In the presence of the little group, thus gathered together, the experiment was repeated: electric sparks were again drawn, in rapid succession, from the iron rod; the prediction of Franklin was fulfilled to the letter; and the identity of Lightning and electricity was, for the first time, demonstrated to the world.

Franklin's Experiment.—Meanwhile Franklin had been waiting, with impatience, for the completion of the tower of Christchurch, in Philadelphia, on which he intended to make the experiment himself. He even collected money, it is said, to hasten on the building. But, notwithstanding his exertions, the progress of the tower was slow; and his active mind, which could ill brook delay, hit upon another expedient, remarkable alike for its simplicity and for its complete success. He constructed a boy's kite, using, however, a silk pockethandkerchief, instead of paper, that it might not be damaged by rain. To the top of the kite he attached a pointed iron wire, about a foot long, and he provided a roll of hempen twine, which he knew to be a conductor of electricity, for flying it. This was the apparatus with which he proposed to explore the nature of a Thundercloud.

The Thundercloud came late in the afternoon of the fourth of July, 1752, and Franklin sallied out with his kite, accompanied by his son, and taking with him a common door-key and a Leyden Jar. The kite was soon high in air, and the philosopher awaited the result of his experiment, standing with his son under the lee of a cowshed, partly to protect himself from the rain that was coming, and partly, it is said, to shield himself from the ridicule of passers-by, who, having no sympathy with his philosophical speculations, might be inclined to regard him as a lunatic. To guard against the danger of receiving a flash of Lightning through his body, he held the kite by means of a silk ribbon, which was tied to the door-key, the door-key being itself attached to the lower end of the hempen string.

A flash of Lightning soon came from the cloud, and a second, and a third; but no sign of electricity could be observed in the kite, or the hempen cord, or the key. Franklin was almost beginning to despair of success, when suddenly he noticed that the little fibres of the cord began to bristle up, just as they would if it were placed near an electric machine in action. He presented the door-key to the knob of the Leyden Jar, and a spark passed between them. Presently a shower began to fall: the cord, wetted by the rain, became a better conductor than it had been before, and sparks came more freely. With these sparks he now charged the Leyden Jar; and found, to his intense delight, that he could exhibit all the phenomena of electricity, by means of the Lightning he had drawn from the clouds.

In the following year, a similar experiment, with even more striking results, was carried out, in France, by de

Romas. Though it is said he had no knowledge of what Franklin had done in America, he too used a kite; and, with a view of making the string a better conductor, he interlaced with it a thin copper wire. Then flying his kite in the ordinary way, when it had risen to a height of about 550 feet, he drew sparks from it which, we are told, were upwards of nine feet long, and emitted a sound like the report of a pistol.

Fatal Experiment of Richman.—There can be no doubt that experiments of this kind, made with the electricity of a Thundercloud, were extremely dangerous; and this was soon proved by a fatal accident. Professor Richman, of St. Petersburgh, had erected on the roof of his house a pointed iron rod, the lower end of which passed into a glass vessel, intended, as we are informed, to measure the strength of the charge which he expected to receive from the clouds. On the sixth of August, 1753, observing the approach of a Thunderstorm, he hastened to his apparatus; and, as he stood near it, with his head bent down, to watch the effect, a flash of Lightning passed through his body, and killed him on the spot. This catastrophe served to fix public attention on the danger of such experiments, and gave occasion to the saying of Voltaire: "There are some great lords whom we should always approach with extreme precaution, and Lightning is one of them."[1] From this time, the practice of making experiments directly with the Lightning of the clouds seems to have been, by common consent, abandoned.

[1] "Il y a des grands seigneurs dont il ne faut approcher qu'avec d'extrêmes précautions. Le tonnerre est de ce nombre."—Dict. Philos. art. Foudre.

Immediate cause of Lightning.—And now, having set before you some of the most memorable experiments by which the identity of Lightning and electricity has been demonstrated, I will try to give you a clear conception regarding the immediate cause of Lightning, so far as the subject is understood, at the present day, by scientific men. You know that there are two kinds of electricity, which are called *positive* and *negative;* and that each of them repels electricity of the same kind as itself, while it attracts electricity of the opposite kind. Now, every Thundercloud is charged with electricity of one kind or the other, positive or negative: and, as it hovers over the earth, it develops, by what is called *induction*, or influence, electricity of the opposite kind, in that part of the earth which is immediately under it. Thus, we have two bodies—the cloud and the earth—charged with opposite kinds of electricity, and separated by a stratum of the atmosphere. The two opposite electricities powerfully attract each other; but, for a time, they are prevented from rushing together, by the intervening stratum of air, which is a non-conductor of electricity, and acts as a barrier between them. As the electricity, however, continues to accumulate, the attraction becomes stronger and stronger, until at length it is able to overcome the resistance of this barrier; a violent disruptive discharge then takes place between the cloud and the earth; and the flash of Lightning is the consequence of the discharge.

The whole phenomenon may be illustrated, on a small scale, by means of this electric machine of Carré's which you see before you. When my assistant turns the handle of the machine, negative electricity is developed in that

large brass cylinder, which in our experiment will represent the Thundercloud. At a distance of five or six inches from the cylinder, I hold a brass ball, which is in electrical communication with the earth through my body. The electrified brass cylinder acts by induction, or influence, on the brass ball, and develops in it, as well as in my body, a charge of positive electricity. Now, the positive electricity of the ball, and the negative electricity of the cylinder, are mutually attracting each other, but the intervening stratum of air offers a resistance, which prevents a discharge from taking

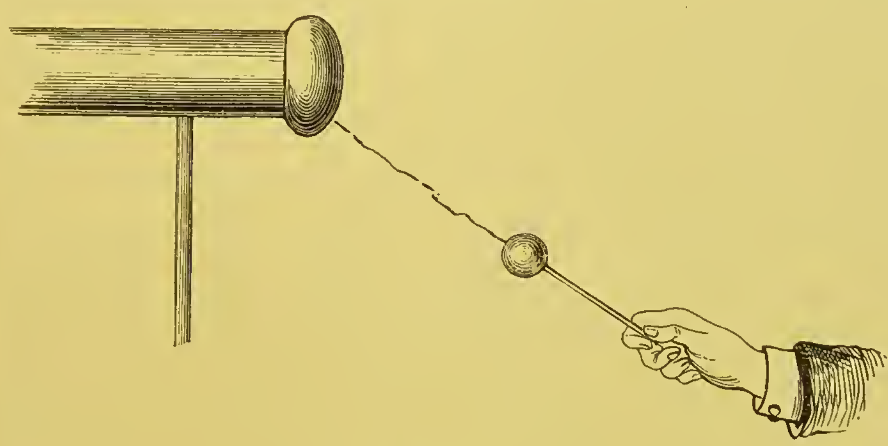

Fig. 9.

The Electric Spark; a Type of a Flash of Lightning.

place. My assistant, however, continues to work the machine; the two opposite electricities rapidly accumulate on the cylinder and the ball; at length, their mutual attraction is strong enough to overcome the resistance interposed between them; a disruptive discharge follows, and at the same moment a spark is seen to pass, accompanied by a sharp snapping report.

This spark is a miniature flash of Lightning; and the snapping report is a diminutive peal of Thunder. Furthermore, at the moment the spark passes, you may observe a slight convulsive movement in my hand and wrist. This convulsive movement represents, on a small scale, the violent shock, generally fatal to life, which is produced by a flash of Lightning when it passes through the body.

I can continue to take sparks from the conductor as long as the machine is worked; and it is interesting to observe that these sparks follow an irregular zig-zag course, just as Lightning does. The reason is the same in both cases: a discharge between two electrified bodies takes place along the line of least resistance; and, owing to the varying condition of the atmosphere, as well as of the minute particles of matter floating in it, the line of least resistance is almost always a zig-zag line.

What a Flash of Lightning is.—Lightning, then, may be conceived as an electrical discharge, sudden and violent in its character, which takes place, through the atmosphere, between two bodies highly charged with opposite kinds of electricity. Sometimes this electrical discharge passes, as I have said, between a cloud and the earth; sometimes it passes between one cloud and another; sometimes, on a smaller scale, it takes place between the great mass of a cloud and its outlying fragments.

But, if you ask me in what the discharge itself consists, I am utterly unable to tell you. It is usual to speak and write on this subject as if electricity were a material substance, a very subtle fluid, and as if, at the moment the discharge takes place, this fluid passes, like a rapid stream,

from the body that is positively electrified to the body that is negatively electrified. But we must always remember that this is only a conventional mode of expression, intended chiefly to assist our conceptions, and to help us to talk about the phenomena. It does not even profess to represent the objective truth. All that we know for certain is this: that immediately before the discharge, the two bodies are highly electrified with opposite kinds of electricity; and, that immediately after the discharge, they are found to have returned to their ordinary condition, or, at least, to have become less highly electrified than they were before.

The flash of light that accompanies an electric discharge is often supposed to be the electricity itself, passing from one body to the other. But it is not: it is simply an effect produced by the discharge. Heat is generated by the expenditure of electrical energy, in overcoming the resistance offered by the atmosphere; and this heat is so intense, that it produces a brilliant incandescence along the path of the discharge. When a spark appears, for example, between the conductor of the machine and this brass ball, it can be shown, by very satisfactory evidence, that minute particles of these solid bodies are first converted into vapour, and then made to glow with intense heat. The gases, too, of which the air is composed, and the solid particles floating in the air, are likewise raised to incandescence. So, too, with Lightning: the flash of light is due to the intense heat generated by the electrical discharge, and owes its character to the composition and the density of the atmosphere through which the discharge passes.

Duration of a Flash of Lightning.—How long does a flash of Lightning last? You are aware, I dare say, that when an impression of light is made on the eye, the impression remains for a sensible interval of time, not less than the tenth of a second, after the source of light has been extinguished or removed. Hence we continue, in fact, to see the light, for at least the tenth of a second, after the light has ceased. Now, if you reflect how brief is the moment for which a flash of Lightning is visible, and if you deduct the tenth of a second from that brief moment, you will see, at once, that the period of its actual duration must be very short indeed.

The exact duration of a flash of Lightning is a question on which no settled opinion has yet been accepted generally by scientific men. Indeed, the most widely different statements have been made on the subject, quite recently, by the highest authorities, each speaking apparently with unhesitating confidence. Thus, for example, Professor Mascart describes an experiment, which he says was made by Wheatstone, and which showed that a flash of Lightning lasts for less than *one*-thousandth of a second[1]; Professor Everett describes the same experiment, without saying by whom it was made, and gives, as the result, that "the duration of the illumination produced by Lightning is certainly less than the *ten*-thousandth of a second"[2]; Professor Tyndall, in his own picturesque way, tells us that "a flash of Lightning cleaves a cloud, appearing and disappearing in less than the *hundred*-thousandth of a

[1] Electricité Statique, ii. 561.

[2] Deschanel's Natural Philosophy, Sixth Edition, p. 641.

second"[1]; and according to Professor Tait, of Edinburgh, "Wheatstone has shown that Lightning certainly lasts less than the *millionth* of a second."[2]

Experiments of Professor Rood.—I cannot say which of these statements is best supported by actual observation; for none of the writers I have quoted gives any reference to the original memoir from which his statement is derived. As far as my own reading goes, I have only come across one original record of experiments, made directly on the flash of Lightning itself, with a view to determine the period of its duration. These experiments were carried out by Professor Ogden Rood, of Columbia College, New York, between the years 1870 and 1873, and are recorded in the American Journal of Science and Arts.[3]

For the description of his apparatus, and for the details of his observations, I must refer you to the memoir itself; but I may tell you briefly that the results at which he arrived, if they be accepted, must lead to a considerable modification of the views previously entertained on the subject. In the first place, he satisfied himself that what appears to the eye a single flash of Lightning is usually, if not always, multiple in its character; consisting, in fact, of a succession of distinct flashes, which follow one another with such rapidity as to make a continuous impression on the retina. Next, he proceeded to measure approximately the duration of these several component flashes; and he found that it varied over a wide range, amounting sometimes to fully

[1] Fragments of Science, Fifth Edition, p. 311.
[2] Lecture on Thunderstorms, Nature, vol. xxii., p. 341.
[3] Third Series, vol. v., p. 161.

the twentieth of a second, and being sometimes less than the sixteen-hundreth of a second.

Wheatstone's Experiments.—These results are extremely interesting; but we can hardly regard them as finally established, until they have been confirmed by other observers. I may remark, however, that they fit in very well with the experiments made by Professor Wheatstone, many years ago, on the duration of the electric spark, which, as I told you, is a miniature flash of Lightning. In these classical experiments, which leave nothing to be desired in point of accuracy, Professor Wheatstone showed that a spark taken directly from a Leyden Jar, or a spark taken from the conductor of a powerful electric machine, that is, just such a spark as you have seen here to-day, lasts for less than the millionth of a second.

But he also showed that the duration of the spark is greatly increased, when a resisting wire is introduced into the path of the discharge. Thus, for example, when the discharge from a Leyden Jar was made to pass through half a mile of copper wire, with breaks at intervals, the sparks that appeared at these breaks were found to last for $\frac{1}{24,000}$ of a second.[1] Hence we should naturally expect that the period of illumination would be still further increased, in the case of a flash of Lightning, where the resistance interposed is enormously greater than in either of the experiments made by Wheatstone.[2]

[1] Phil. Trans. Royal Society, 1834, vol. cxxv., pp. 583–591.

[2] In experiments with a Leyden Jar, Feddersen has shown that the duration of the discharge is increased, not only by increasing the striking distance, but also by increasing the size of the Jar. Now, a flash of Lightning may be

Experiment of the Rotating Disc.—It would be tedious, on an occasion like the present, to enter into an account of Wheatstone's beautiful and ingenious method of investigation, by which the above facts have been established.

FIG. 10.

CARDBOARD DISC AS SEEN WHEN AT REST.

But I will show you a much more simple experiment, which brings home very forcibly to the mind how exceedingly short must be the duration of the electric spark.

regarded as the discharge of a Leyden Jar of immense size, with an enormous striking distance; and therefore we should expect that the duration of the discharge should be greatly prolonged. See American Journal of Science and Arts, Third Series, vol. i., p. 15.

Here is a circular disc of cardboard, the outer part of which, as you see, is divided into sectors, black and white alternately, while the space about the centre is entirely white. The disc is mounted on a stand, by means of which I can make it rotate with great velocity. When

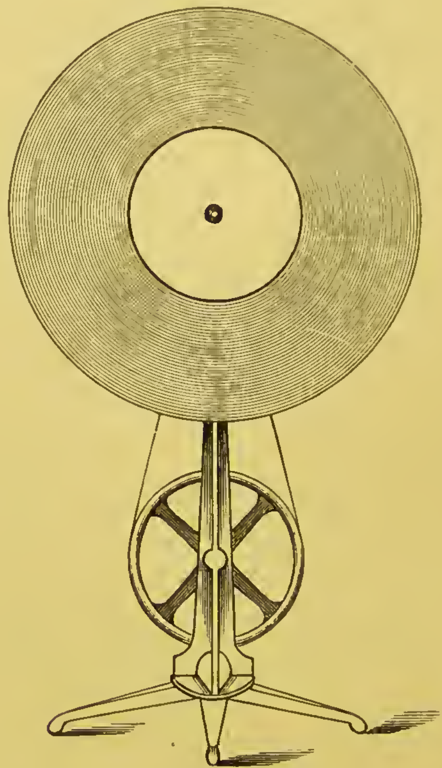

Fig. 11.

Same Disc as seen when in rapid Rotation.

it is put in rotation, the effect on the eye is very striking: the central space remains white as before, but in the outer rim, the distinction of black and white absolutely disappears, and gives places to a uniform gray. This

colour is due to the blending together of black and white in equal proportions; the blending being effected, not on the cardboard disc, but on the retina of the eye.

I mentioned, just now, that an impression made on the retina lasts for the tenth of a second after the cause of it has been removed. Now, when this disc is in rotation, the sectors follow one another so rapidly that the particular part of space occupied, at any moment, by a white sector, will be occupied by a black sector within a time much less than the tenth of a second. It follows, that the impression made by each white sector remains on the retina, until the following black sector comes into the same position; and, in like manner, the impression made by each black sector remains, until the following white sector takes up the position of the black. Therefore the impression made by the whole outer rim is the impression of black and white combined, that is, the impression of gray.

So far, I dare say, the phenomenon is already familiar to you all. But I propose now to show you the revolving disc, illuminated by the electric spark; and you will observe that, at the moment of illumination, the black and white sectors come out as clearly and distinctly as if the disc were standing still.

For the success of this experiment it is desirable, not only to have a brilliant spark, in order to secure a good illumination of the disc, but also to have a succession of such sparks, that you may see the phenomenon frequently repeated, and thus be able to observe it at your leisure. To attain these two objects, I have made the arrangement which is here before you.

In front of the disc is a large and very powerful Leyden Jar. The rod connected with the inner coating rises well above the mouth of the Jar, and ends in a brass ball nearly opposite the centre of the disc. Connected with the outer coating of the Jar is another rod, which likewise ends in a brass ball, and which is so adjusted that the distance between the two balls is about an inch. The two rods are connected respectively with the two conductors of a Holtz machine; so that when the machine is worked, the Jar is first quickly charged, and then it discharges itself, with a brilliant spark, between the two brass balls. Thus, by continuing to work the machine, we can get, as long as we choose, a succession of sparks following one another, at short and regular intervals, right in front of the disc.

Everything being now ready, and the room partially darkened, the disc is put in rapid rotation; and you can see, by the twilight that remains, the outer rim a uniform gray, and the central space white. But when my assistant begins to turn the Holtz machine, and brilliant sparks leap out at intervals, the revolving disc, illuminated for a moment at each discharge, seems to be standing still, and shows the black and white sectors distinctly visible.

The reason of this is clear. So brief is the moment for which the spark endures that the disc, though in rapid motion, makes no sensible advance during that small fraction of time; therefore, in the image on the retina, the impression made by the white sectors remains distinct from the impression made by the black; and the eye sees the disc as it really is.

I may notice, in passing, a very interesting consideration, suggested by this experiment. A cannon ball is now commonly discharged with a velocity of about 1600 feet a second. Moving with this velocity it is, as you know, under ordinary circumstances, altogether invisible to the eye. But suppose it were illuminated, in the darkness of night, by this electric spark, which lasts, we will say, for the millionth of a second. During the moment of illumination, the cannon ball moves through the millionth part of 1600 feet, which is a little less than the fiftieth of an inch. Practically, we may say that the cannon ball does not sensibly change its place while the spark lasts. Further, the impression it makes on the eye, from the position it occupies at the moment of illumination, remains on the retina for at least the tenth of a second. Therefore, if we are looking towards that particular part of space where the cannon ball happens to be, at the moment the spark passes, we must see the cannon ball hanging motionless in the air, though we know it is travelling at the rate of 1600 feet a second, or about 1000 miles an hour.

Brightness of a Flash of Lightning.—I should like to say one word about the brightness of a flash of Lightning. Somewhat more than thirty years ago, Professor Swan, of Edinburgh, showed that the eye requires a sensible time—about the tenth of a second—to perceive the full brightness of a luminous object. Further, he proved, by a series of interesting experiments, that when a flash of light lasts for less than the tenth of a second, its apparent brilliancy to the eye is proportional to the time of its duration.[1] Now consider

[1] See original Paper by Swan, Trans. Royal Society, Edinburgh, 1849, vol. xvi. pp. 581–603; also, a second Paper, ib. 1861, vol. xxii. pp. 33–39.

the consequence of these facts in reference to the brightness of our electric spark. If the spark lasted for the tenth of a second, we should perceive its full brightness; if it lasted for the tenth part of that time, we should see only the tenth part of its brightness; if it lasted for the hundreth part, we should see only the hundredth part of its brightness; and so on. But we know, in point of fact, that it lasts for less than the millionth of a second, that is, less than the hundred-thousandth part of the tenth of a second. Therefore we see only the hundred-thousandth part of its real brightness.

Here is a startling conclusion, and one, I may say, fully justified by scientific evidence. That electric spark, brilliant as it appears to us, is really a hundred thousand times as bright as it seems to be. We cannot speak with the same precision of a flash of Lightning; because its duration has not yet been so exactly determined. But if we suppose that a flash of Lightning, in a particular case, lasts for the thousandth of a second, it would follow, from the above experiments, that the flash is a hundred times as bright, in fact, as it appears to the eye.

Various forms of Lightning.—The Lightning of which I have spoken hitherto is commonly called *forked* Lightning: a name which seems to have been derived from the zig-zag line of light it presents to the eye. But there are other forms under which the electricity of the clouds often makes itself manifest; and to these I would now invite your attention for a few moments. The most common of them all, at least in this country, is that which is familiarly known by the name of *sheet* Lightning. This is, probably, nothing else

than the lighting up of the atmosphere, or of the clouds, by forked Lightning, which is not itself directly visible.

Generally speaking, after a flash of sheet Lightning, we hear the rolling of distant Thunder. But it sometimes happens, especially in summer time, that the atmosphere is, again and again, lit up by a sudden glow of light, and yet no Thunder is heard. This phenomenon is commonly called *summer* Lightning, or *heat* Lightning. It is probably due, in many cases, to electrical discharges in the higher regions of the atmosphere, where the air is greatly rarified; and, in these cases, it would seem to resemble the discharges obtained, by means of an induction coil, in glass tubes containing rarified gases. But there is little doubt that in many cases, too, summer Lightning, like ordinary sheet Lightning, is due to forked Lightning, which is so remote that we can neither see the flash itself directly, nor hear the rolling of the Thunder.

Perhaps the most distinct and satisfactory evidence, on this subject, derived from actual observation, is contained in the following letter of Professor Tyndall, written in May, 1883: "Looking to the south and south-east from the Bel Alp, the play of silent Lightning among the clouds and mountains is sometimes very wonderful. It may be seen palpitating for hours, with a barely appreciable interval between the thrills. Most of those who see it regard it as Lightning without Thunder—Blitz ohne Donner, Wetterleuchten, I have heard it named by German visitors. The Monte Generoso, overlooking the Lake of Lugano, is about fifty miles from the Bel Alp, as the crow flies. The two points are connected by telegraph; and frequently when

the Wetterleuchten, as seen from the Bel Alp, was in full play, I have telegraphed to the proprietor of the Monte Generoso Hotel, and learned, in every instance, that our silent Lightning co-existed in time with a Thunderstorm more or less terrific in Upper Italy."[1]

Another form of Lightning, described by many writers, is called *globe* Lightning. It is said to appear as a ball of fire, about the size of a child's head, or even larger, which moves for a time slowly about, and then, after the lapse of several seconds, explodes with a terrific noise, sending forth flashes of fire in all directions, which burn whatever they strike. Many accounts are on record of such phenomena; but they are derived, for the most part, from the evidence of persons who were not specially competent to observe, and to describe with precision, the facts that fell under their observation. Hence these accounts, while they are accepted by some, are rejected by others; and it seems to me, in the present state of the question, that the existence of globe Lightning can hardly be regarded as a demonstrated fact. At all events, if phenomena of this kind have really occurred, I can only say that nothing we know about electricity, at present, will enable us to account for them.[2]

St. Elmo's Fire.—A much more authentic and, at the same time, very interesting form, under which the electricity

[1] Nature, vol. xxviii. p. 54.

[2] See, however, an attempt to account for this phenomenon in de Larive's Treatise on Electricity, London, 1853–8, vol. iii. pp. 199, 200; and another, quite recently, by Mr. Spottiswoode, in a Lecture on the Electrical Discharge, delivered before the British Association at York, in September, 1881, and published by Longmans, London, p. 42. See also, for recent evidence regarding the phenomenon itself, Scott's Elementary Meteorology, pp. 175–8.

of the clouds sometimes manifests its presence, is known by the name of St. Elmo's fire. This phenomenon at one time presents the appearance of a star, shining at the points of the lances or bayonets of a company of soldiers; at another, it takes the form of a tuft of bluish light, which seems to stream away from the masts and spars of a ship at sea, or from the pointed spire of a church. It was well known to the ancients. Cæsar, in his Commentaries, tells us that, after a stormy night, the iron points of the javelins of the fifth legion seemed to be on fire; and Pliny says that he saw lights, like stars, shining on the lances of the soldiers, keeping watch by night upon the ramparts. When two such lights appeared at once, on the masts of a ship, they were called Castor and Pollux, and were regarded by sailors as a sign of a prosperous voyage. When only one appeared, it was called Helen, and was taken as an unfavourable omen.

In modern times, St. Elmo's fire has been witnessed by a host of observers, and all its various phases have been repeatedly described. In the memoirs of Forbin, we read that when he was sailing once, in 1696, among the Balearic Islands, a sudden storm came on during the night, accompanied by Lightning and Thunder. "We saw on the vessel," he says, "more than thirty St. Elmo's fires. Amongst the rest there was one on the vane of the mainmast, more than a foot and a-half high. I sent a man up to fetch it down. When he was aloft, he cried out that it made a noise like wetted gunpowder set on fire. I told him to take off the vane, and come down; but scarcely had he removed it from its place when the fire left it, and reappeared at the

end of the mast, so that it was impossible to take it away. It remained for a long time and gradually went out."

On the fourteenth of January, 1824, Monsieur Maxadorf happened to look at a load of straw, in the middle of a field, just under a dense black cloud. The straw seemed literally on fire; a streak of light went forth from every blade; even the driver's whip shone with a pale-blue flame. As the black cloud passed away, the light gradually disappeared, after having lasted about ten minutes. Again, it is related that on the eighth of May, 1831, in Algiers, as the French artillery officers were walking out, after sunset, without their caps, each one saw a tuft of blue light on his neighbour's head; and when they stretched out their hands, a tuft of light was seen at the end of every finger. Not unfrequently a traveller in the Alps sees the same luminous tuft on the point of his Alpenstock. And quite recently, during a Thunderstorm, a whole forest was observed to become luminous just before each flash of Lightning, and to become dark again at the moment of the discharge.[1]

This phenomenon may be easily explained. It consists in a gradual and comparatively silent electrical discharge between the earth and the cloud; and generally, but not always, it has the effect of preventing such an accumulation of electricity as would be necessary to produce a flash of Lightning. I can illustrate this kind of discharge with the aid of our machine. If I hold a pointed metal rod towards the large conductor, you can see, when the machine is worked,

[1] See Jamin, Cours de Physique, i. 480–1; Tomlinson, The Thunderstorm, Third Edition, pp. 95–103; Thunderstorms, a Lecture by Professor Tait, Nature, vol. xxii. p. 356.

and the room darkened, how the point of the rod becomes luminous, and shines like a faint blue star. I substitute for the pointed rod the blunt handles of a pair of pliers, and a tuft of blue light is at once developed at the end of each handle, and seems to stream away with a hissing noise. I now put aside the pliers, and open out my hand under

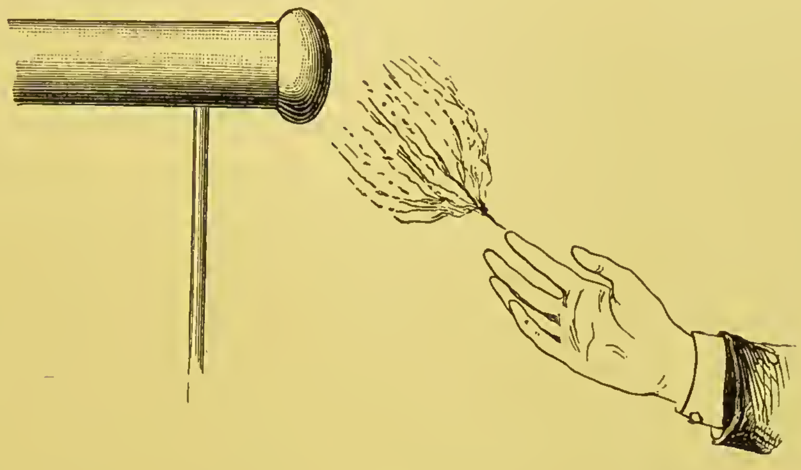

FIG. 12.

THE BRUSH DISCHARGE, ILLUSTRATING ST. ELMO'S FIRE.

the conductor; and observe how I can set up, at pleasure, a luminous tuft at the tips of my fingers. Now and then a spark passes, giving me a smart shock, and showing how the electricity may sometimes accumulate so fast that it cannot be sufficiently discharged by the luminous tuft. Lastly, I present a small bushy branch of a tree to the conductor, and all its leaves and twigs are aglow with bluish light, which ceases for a moment when a spark escapes, to be again renewed when electricity is again developed by the working of the machine.

Now, if you put a Thundercloud in the place of that conductor, you can easily realize how, through its influence, the lance and bayonet of the soldier, the Alpenstock of the traveller, the pointed spire of a church, the masts of a ship at sea, the trees of a forest, can all be made to glow with a silent electrical discharge, which may or may not, according to circumstances, culminate at intervals in a genuine flash of Lightning.

Origin of Lightning.—When we seek to account for the origin of Lightning we are confronted, at once, with two questions of great interest and importance: first, What are the sources from which the electricity of the Thundercloud is derived? and, secondly, How does this electricity come to be developed in a form which so far transcends, in power, the electricity of our machines? These questions have long engaged the attention of scientific men; but I cannot say that they have yet received a perfectly satisfactory solution. Nevertheless, some facts of great scientific value have been established, and some speculations have been put forward, which are well deserving of consideration.

In the first place, it is quite certain that the atmosphere which surrounds our globe is almost always in a state of electrification. Further, the electrical condition of the atmosphere would seem to be as variable as the wind. It changes with the change of season; it changes from day to day; it changes from hour to hour. The charge of electricity is sometimes positive, sometimes negative; sometimes it is strong, sometimes feeble; and the transition from one condition to another is sometimes slow and gradual, sometimes sudden and violent.

As a general rule, in fine clear weather, the electricity of the atmosphere is positive, and not very strongly developed. In wet weather, the charge may be either positive or negative, and is generally strong, especially when there are sudden heavy showers. In fog, it is also strong, and almost always positive. In a Snowstorm, it is very strong, and most frequently positive. Finally, in a Thunderstorm, it is extremely strong, and generally negative; but it is subject to a sudden change of sign, when a flash of Lightning passes, or when rain begins to fall.

So far I have simply stated facts, which have been ascertained by careful observations, made at different stations by competent observers, and extending over a period of many years. But as regards the process by which the electricity of the atmosphere is developed, we have, up to the present time, no certain knowledge. It has been said that electricity may be generated in the atmosphere by the friction of the air itself, and of the minute particles floating in it, against the surface of the earth, against trees and buildings, against rocks, cliffs, and mountains. But this opinion, however probable it may be, has not yet been confirmed by any direct experimental investigation.

The second theory is that the electricity of the atmosphere is due, in great part at least, to the evaporation of salt water. Many years ago, Pouillet, a French philosopher, made a series of experiments in the laboratory, which seemed to show that evaporation is generally attended with the development of electricity; and, in particular, he satisfied himself that the vapour which passes off from the

surface of salt water is always positively electrified. Now, the atmosphere is everywhere charged, more or less, with vapour which comes, almost entirely, from the salt water of the ocean. Hence Pouillet inferred that the chief source of atmospheric electricity is the evaporation of sea water. This explanation would certainly go far to account for the presence of electricity in the atmosphere, if the fact on which it rests were established beyond dispute. But there is some reason to doubt whether the development of electricity, in the experiments of Pouillet, was due simply to the process of evaporation, and not rather to other causes, the influence of which he did not sufficiently take into account.

A conjecture has recently been started, that electricity may be generated by the mere impact of minute particles of water vapour against minute particles of air.[1] If this conjecture could be established as a fact, it would be amply sufficient to account for all the electricity of the atmosphere. From the very nature of a gas, the molecules of which it is composed are, for ever, flying about with incredible velocity; and therefore the particles of water vapour and the particles of air, which exist together in the atmosphere, must be incessantly coming into collision. Hence, however small may be the charge of electricity developed at each individual impact, the total amount generated over any considerable area, in a single day, must be very great indeed. It is evident, however, that this method of explaining the origin of atmospheric electricity can only be regarded as,

[1] Professor Tait, On Thunderstorms, Nature, vol. xxii., pp. 436–7.

at best, a probable hypothesis, until the assumption on which it rests is supported by the evidence of observation or experiment.

Length of a Flash of Lightning.—It would seem, then, that we are not yet in a position to indicate with certainty the sources from which the electricity of the atmosphere is derived. But whatever these sources may be, there can be little doubt that the electricity of the atmosphere is intimately associated with the minute particles of water vapour of which the Thundercloud is eventually built up. This consideration is of great importance, when we come to consider the special properties of Lightning, as compared with other forms of electricity. The most striking characteristic of Lightning is the wonderful power it possesses of forcing its way through the resisting medium of the air. In this respect it incomparably surpasses all forms of electricity that have hitherto been produced by artificial means. The spark of an ordinary electric machine can leap across a space of three or four inches: the machine we have employed in our experiments to-day can give, under favourable circumstances, a spark of nine or ten inches: the longest electric spark ever yet produced artificially is probably the spark of Mr. Spottiswoode's gigantic Induction Coil; and it does not exceed three feet six inches. But the length of a flash of Lightning is not to be measured in inches, or in feet, or in yards; it varies from one or two miles, for ordinary flashes, to eight or ten miles in exceptional cases.

This power of discharging itself violently through a resisting medium, in which the Thundercloud so far transcends the conductor of an electric machine, is due to the

property commonly known among scientific men as electrical *Potential*. The greater the distance to which an electrified body can shoot its flashes through the air, the higher must be its Potential. Hence the Potential of a Thundercloud must be exceedingly high; since its flashes can pierce the air to a distance of several miles. And what I want to point out is, that we are able to account for this exceedingly high Potential, if we may only assume that the minute particles of water vapour in the atmosphere have, from any cause, received ever so small a charge of electricity. The number of such particles that go to make up an ordinary drop of rain are to be counted by millions of millions; and it is capable of scientific proof that, as each new particle is added, in the building up of the drop, a rise of Potential is necessarily produced. It is clear, therefore, that there is practically no limit to the Potential that may be developed by the simple agglomeration of very small cloud particles, each carrying a very small charge of electricity.[1]

This explanation, which traces the exceedingly high Potential of Lightning to the building up of rain drops in the Thundercloud, suggests a reason why it so often happens that, immediately after a flash of Lightning, "the big rain comes dancing to the earth." The Potential has been steadily rising as the drops have been getting larger and larger; until, at length, the Potential has become so high that the Thundercloud is able to discharge itself, and almost at the same moment the drops have become so large that they can no longer be held aloft against the attracting force of gravity.

[1] See note at the end of this Lecture, p. 92.

Physical Cause of Thunder.—Let us now proceed to consider the phenomenon of Thunder, which is so intimately associated with Lightning, and which, though perfectly harmless in itself, and though never heard until the real danger is passed, often excites more terror in the mind than the Lightning flash itself. The sound of Thunder, like that of the electric spark, is due to a disturbance caused in the air by the electric discharge. The air is first expanded by the intense heat that is developed along the line of discharge, and then it rushes back again to fill up the partial vacuum which its expansion has produced. This sudden movement gives rise to a series of sound waves, which reach the ear in the form of Thunder. But there are certain peculiar characteristics of Thunder, which are deserving of special consideration.

Rolling of Thunder.—They may be classified, I think, under two heads. First, the sound of Thunder is not an instantaneous report, like the sound of the electric spark: it is a prolonged peal, lasting sometimes for several seconds. Secondly, each flash of Lightning gives rise, not to one peal only, but to a succession of peals following one another at irregular intervals. These two phenomena, taken together, produce that peculiar effect on the ear which is commonly described as the *rolling* of Thunder; and both of them, I think, may be sufficiently accounted for in accordance with the well-established properties of sound.

To understand why the sound of Thunder reaches the ear as a prolonged peal, we have only to remember that sound takes time to travel. Since a flash of Lightning is practically instantaneous, we may assume that the sound is produced at the same moment, all along the line of discharge. But the

sound waves, setting out at the same moment from all points along the line of discharge, must reach the ear in successive instants of time; arriving first from that point which is nearest to the observer, and last from that point which is most distant. Suppose, for example, that the nearest point of the flash is a mile distant from the observer, and the farthest point, two miles; the sound will take about five seconds to come from the nearest point, and about ten seconds to come from the farthest point: and moreover, in each successive instant, from the time the first sound reaches the ear, sound will continue to arrive from the successive points between. Therefore the Thunder, though instantaneous in its origin, will reach the ear as a prolonged peal, extending over a period of five seconds.

Succession of Peals.—The succession of peals, produced by a single flash of Lightning, is due to several causes, each one of which may contribute more or less, according to circumstances, towards the general effect. First, if we accept the results arrived at by Professor Ogden Rood of Columbia College, what appears to the eye as a single flash of Lightning consists, in fact, as a general rule, of a succession of flashes, each one of which must naturally produce its own peal of Thunder: and although the several flashes, if they follow one another at intervals of the tenth of a second, will make one continuous impression on the eye, the several peals of Thunder, under the same conditions, will impress the ear as so many distinct peals.

The next cause that I would mention is the zig-zag path of the Lightning discharge. To make clear to you the influence of this circumstance, I must ask your attention, for a

moment, to the diagram before you. Let the broken line represent the path of a flash of Lightning, and let O represent the position of an observer. The sound will reach him first from the point A, which is nearest to him; and then it will continue to arrive, in successive instants, from the successive points along the line A N, and along the line A M, thus producing the effect of a continuous

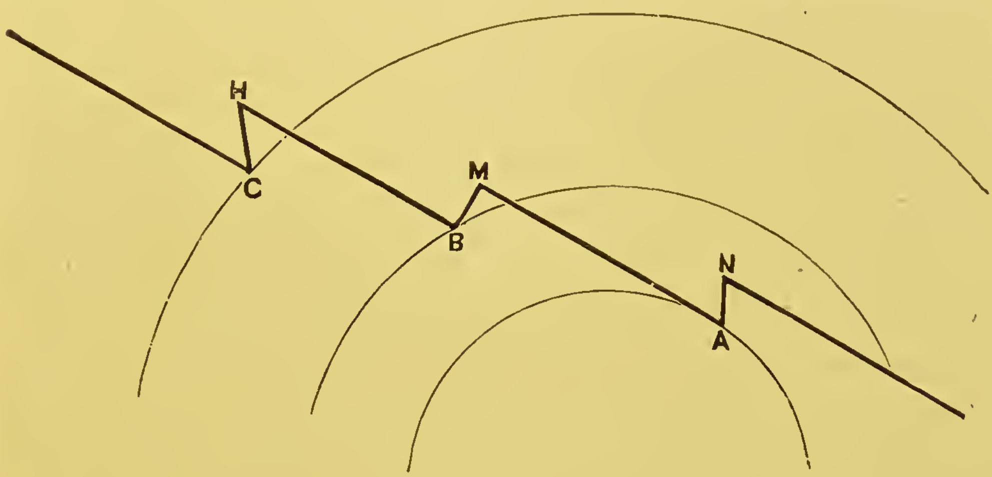

Fig. 13.
Origin of Successive Peals of Thunder.

peal. Meanwhile the sound waves have been travelling from the point B, and in due time will reach the observer at O. Coming as they do in a different direction from the former, they will strike the ear as the beginning of a new peal which, in its turn, will be prolonged by the sound waves arriving, in successive instants, from the successive points along the line B M and B H. A little later, the sound will arrive from the more distant point C, and a third peal will begin. And so, there will be several distinct peals proceeding, so to speak, from several distinct points in the path of the Lightning flash.

A third cause, to which the succession of peals may be referred, is to be found in the minor electrical discharges that must often take place within the Thundercloud itself. A Thundercloud is not a continuous mass, like the metal cylinder of this electric machine: it has many outlying fragments, more or less imperfectly connected with the principal body. Moreover, the material of which the cloud is composed is only a very imperfect conductor, as compared with our brass cylinder. For these two reasons it must often happen, about the time a flash of Lightning passes, that different parts of the cloud will be in such different electrical conditions as to give rise to electrical discharges within the cloud itself. Each of these discharges produces its own peal of Thunder; and thus we may have a number of minor peals, sometimes preceding and sometimes following the great crash which is due to the principal discharge.

Lastly, the influence of echo has often a considerable share in multiplying the number of peals of Thunder. The waves of sound, going forth in all directions, are reflected from the surfaces of mountains, forests, clouds, and buildings, and coming back from different quarters, and with varying intensity, reach the ear like the roar of distant artillery. The striking effect of these reverberations, in a mountain district, has been described by a great poet, in words which, I dare say, are familiar to most of you:

> "Far along,
> From peak to peak, the rattling crags among,
> Leaps the live thunder! not from one lone cloud,
> But every mountain now has found a tongue,
> And Jura answers from her misty shroud,
> Back to the joyous Alps, that call to her aloud!"

Variations of Intensity in Thunder.—From what has been said, it is easy to understand how the general roar of Thunder is subject to great changes of intensity, during the time it lasts, according to the number of peals that may be arriving at the ear of an observer in each particular moment. But every one must have observed that even an individual peal of Thunder often undergoes similar changes, swelling out at one moment with great power, and the next moment rapidly dying away. To account for this phenomenon, I would observe, first, that there is no reason to suppose that the disturbance caused by Lightning is of exactly the same magnitude at every point of its path. On the contrary, it would seem very probable that the amount of this disturbance is, in some way, dependent on the resistance which the discharge encounters. Hence the intensity of the sound waves, sent forth by a flash of Lightning, is probably very different at different parts of its course; and each individual peal will swell out on the ear, or die away, according to the greater or less intensity of the sound waves that reach the ear in each successive moment of time.

But there is another influence at work, which must produce variations in the loudness of a peal of Thunder, even though the sound waves, set in motion by the Lightning, were everywhere of equal intensity. This influence depends on the position of the observer in relation to the path of the Lightning flash. At one part of its course, the Lightning may follow a path which remains, for a certain length, at nearly the same distance from the observer ; then all the sound produced along this length will reach the observer nearly at the same moment, and will burst upon the ear with

great intensity. At another part, the Lightning may, for an equal length, go right away from the observer; and it is evident that the sound produced along this length will reach the observer in successive instants, and consequently produce an effect comparatively feeble.

With a view to investigate this interesting question a little more closely, let me suppose the position of the observer taken as a centre, and a number of concentric circles drawn, cutting the path of the Lightning flash, and separated from one another by a distance of 110 feet, measured along the direction of the radius. It is evident that all the sound produced between any two consecutive circles, will reach the ear within a period which must be measured by the time that sound takes to travel 110 feet, that is, within the tenth of a second. Hence, in order to determine the quantity of sound that reaches the ear in successive periods of one-tenth of a second, we have only to observe how much is produced between each two consecutive circles. But on the supposition that the sound waves, set in motion by the flash of Lightning, are of equal intensity at every point of its path, it is clear that the quantity of sound developed between each two consecutive circles will be simply proportional to the length of the path enclosed between them.

With these principles established, let us now follow the course of a peal of Thunder, in the diagram before us. This broken line, drawn almost at random, represents the path of a flash of Lightning; the observer is supposed to be placed at O, which is the centre of the concentric circles; these circles are separated from one another by a distance of 110 feet, measured in the direction of the radius; and we want to consider how

any one peal of Thunder may vary in loudness in the successive periods of one-tenth of a second.

Let us take, for example, the peal which begins when the sound waves reach the ear from the point A. In the first unit of time the sound that reaches the ear is the sound produced along the lines A B and A C; in the second unit, the sound produced along the lines B D and C E; in the third unit, the sound produced along D F and E G. So far the peal has been fairly uniform in its intensity; though there has been a slight falling off in the second and third units of time, as compared with the first. But in the fourth unit there is a considerable falling away of the sound; for the line F K is only about

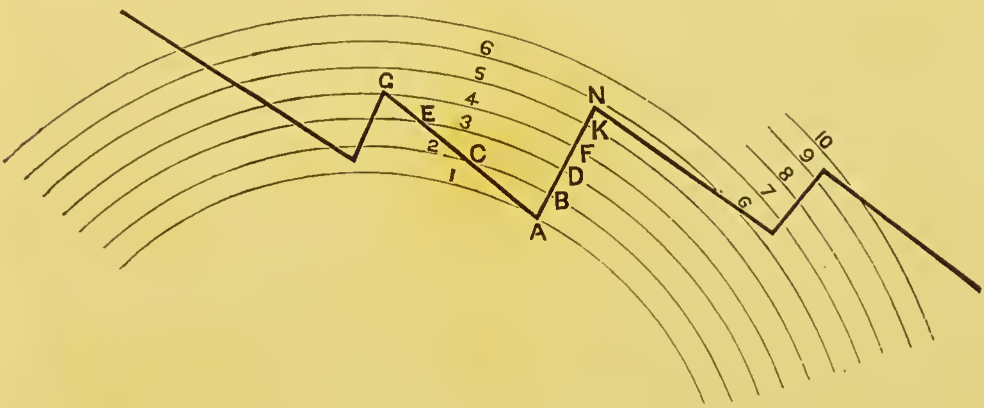

FIG. 14.

VARIATIONS OF INTENSITY IN A PEAL OF THUNDER.

one-third as long as D F and E G taken together: therefore the quantity of sound, that reaches the ear in the fourth unit of time, is only one-third of that which reaches it in each of the three preceding units; and consequently the sound is

only one-third as loud. In the fifth unit, however, the peal must rise to a sudden crash; for the portion of the Lightning path enclosed between the fifth and sixth circles is about six times as great as that between the fourth and fifth; therefore the intensity of the sound will be suddenly increased about six-fold. After this sudden crash, the sound as suddenly dies away in the sixth unit of time; it continues feeble as the path of the Lightning goes nearly straight away from the observer; it swells again slightly in the ninth unit of time; and then continues without much variation to the end. This is only a single illustration; but it seems quite sufficient to show that the changes of intensity in a peal of Thunder must be largely due to the position of the spectator in relation to the several parts of the Lightning flash.

Distance of a Flash of Lightning.—I need hardly remind you that, by observing the interval that elapses between the flash of Lightning and the peal of Thunder that follows it, we may estimate approximately the distance of the nearest point of the discharge. Light travels with such amazing velocity that we may assume, without any sensible error, that we see the flash of Lightning at the very moment in which the discharge takes place. But sound, as we have seen, takes a sensible time to travel even short distances; and therefore a measurable interval almost always elapses between the moment in which the flash is seen, and the moment in which the peal of Thunder first reaches the ear. And the distance through which sound travels in this interval, will be the distance of the nearest point through which the discharge has passed. Now the velocity of sound in air varies slightly with the

temperature; but, at the ordinary temperature of our climate, we shall not be far astray if we allow 1,100 feet for every second, or about one mile for every five seconds.

You will observe also that, by repeating this observation, we can determine whether the Thundercloud is coming towards us, or going away from us. So long as the interval between each successive flash and the corresponding peal of Thunder, continues to get shorter and shorter, the Thundercloud is approaching: when the interval begins to increase, the Thundercloud is receding from us, and the danger is passed.

The crash of Thunder is terrific when the Lightning is close at hand; but it is a curious fact, that the sound does not seem to travel as far as the report of an ordinary cannon. We have no authentic record of Thunder having been heard at a greater distance than from twelve to fifteen miles: whereas the report of a single cannon has been heard at five times that distance; and the roar of artillery, in battle, at a greater distance still. On the occasion of the Queen's visit to Cherbourg, in August, 1858, the salute fired in honour of her arrival, was heard at Bonchurch, in the Isle of Wight, a distance of sixty miles. It was also heard at Lyme Regis, in Dorsetshire, which is eighty-five miles from Cherbourg, as the crow flies; and we are told that, not only was it audible in its general effect, but the report of individual guns was distinctly recognised. The artillery of Waterloo is said to have been heard at the town of Creil, in France, 115 miles from the field of battle; and the cannonading at the siege of Valenciennes, in 1793, was heard, from day to day,

at Deal, on the coast of England, a distance of 120 miles.[1]

So far, I have endeavoured to set forth some general ideas on the nature and origin of Lightning, and of the Thunder that accompanies it. In my next Lecture, I propose to give a short account of the destructive effects of Lightning, and to consider how these effects may best be averted by means of Lightning Conductors.

Note to Page 82.

On the High Potential of a Flash of Lightning.

The Potential of an electrified sphere is equal to the quantity of electricity with which the sphere is charged, divided by the radius of the sphere. Now the minute cloud particles, which go to make up a drop of rain, may be taken to be very small spheres; and if v represent the Potential of each one, q the quantity of electricity with which it is charged, and r the radius of the sphere, we have $v = \frac{q}{r}$. Suppose 1000 of these cloud particles to unite into one: the quantity of electricity in the drop, thus formed, will be $1000q$; and the radius, which increases in the ratio of the cube root of the volume, will be $10r$. Therefore the Potential of the new sphere will be $\frac{1000q}{10r}$, or $100\frac{q}{r}$; that is to say, it will be 100 times as great as the Potential of each of the cloud particles which compose it. When a million of cloud particles are blended into a single drop, the same process will show that the Potential has been increased ten thousand-fold; and when a drop is produced by the agglomeration of a million of millions of cloud particles, the Potential of the drop will be a hundred million times as great as that of the individual particles.[2]

[1] See Tomlinson, The Thunderstorm, pp. 87–9.

[2] See Tait on Thunderstorms, Nature, vol. xxii., p. 436.

LECTURE II.

LIGHTNING CONDUCTORS.

THE effects of Lightning, on the bodies that it strikes, are analogous to those which may be produced by the discharge of our electric machines and Leyden Jar batteries. When the discharge of a battery traverses a metal conductor, of sufficient dimensions to allow it an easy passage, it makes its way along silently and harmlessly. But if the conductor be so thin as to offer considerable resistance, then the conductor itself is raised to intense heat, and may be melted, or even converted into vapour, by the discharge.

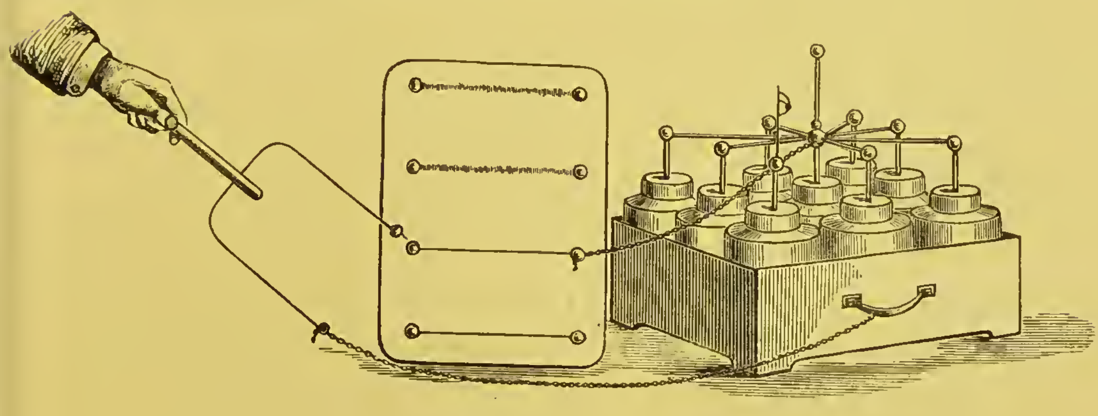

FIG. 15.

DISCHARGE OF LEYDEN JAR BATTERY THROUGH THIN WIRES.

Here is a board on which a number of very thin wires have been stretched, over white paper, between brass balls.

The wires are so thin that the full charge of the battery before you, which consists of nine large Leyden Jars, is quite sufficient to convert them in an instant into vapour. I have already, on former occasions, sent the charge through two of these wires, and nothing remains of them now but the traces of their vapour, which mark the path of the electric discharge from ball to ball. At the present moment the battery stands ready charged, and I am going to discharge it through a third wire, by means of this insulated rod which I hold in my hand. The discharge has passed: you saw a flash, and a little smoke; and now, if you look at the paper, you will find that the wire is gone, but that it has left behind the track of its incandescent vapour, marking the path of the discharge.

Destruction of Buildings by Lightning.—We learn from this experiment that the electricity stored up in our battery passes, without visible effect, through the stout wire of a discharging rod, but that it instantly converts into vapour the thin wire stretched across the spark board. And so it is with a flash of Lightning. It passes harmlessly, as every one knows, through a stout metal rod, but when it comes across bell wires or telegraph wires, it melts them, or converts them into vapour. On the sixteenth of July, 1759, a flash of Lightning struck a house in Southwark, on the south side of London, and followed the line of the bell wire. After the Lightning had passed, the wire was no longer to be found; but the path of the Lightning was clearly marked by patches of vapour which were left, here and there, adhering to the surface of the wall. In the year 1754, the Lightning fell on a bell tower at Newbury, in the United States of America, and

having dashed the roof to pieces, and scattered the fragments about, it reached the bell. From this point it followed an iron wire, about as thick as a knitting needle, melting it as it passed along, leaving behind a black streak of vapour on the surface of the walls.

Again, the electric discharge, passing through a bad conductor, produces mechanical disturbance, and, if the substance be combustible, often sets it on fire. So too, as you know, the Lightning flash, falling on a church spire, dashes it to pieces, knocking the stones about in all directions, while it sets fire to ships and wooden buildings; and more than once it has caused great devastation by exploding powder magazines.

Let me give you one or two examples. In January, 1762, the Lightning fell on a church tower in Cornwall, and a stone, three hundredweight, was torn from its place, and hurled to a distance of 180 feet; while a smaller stone was projected as far as 1200 feet from the building. Again, in 1809, the Lightning struck a house not far from Manchester, and literally moved a massive wall, twelve feet high and three feet thick, to a distance of several feet. You may form some conception of the enormous force here brought into action, when I tell you that the total weight of mason-work moved on this occasion was not less than twenty-three tons.

The Church of St. George, at Leicester, was severely damaged by Lightning on the first of August, 1846. About eight o'clock in the evening, the rector of the parish saw a vivid streak of light, darting with incredible velocity against the upper part of the spire. "For the distance of forty feet

on the eastern side, and nearly seventy on the west, the massive stone work of the spire was instantly rent asunder, and laid in ruins. Large blocks of stone were hurled in all directions, broken into small fragments, and in some cases, there is reason to believe, reduced to powder. One fragment of considerable size was hurled against the window of a house three hundred feet distant, shattering to pieces the woodwork, and strewing the room within with fine dust and fragments of glass. It has been computed that a hundred tons of stone were, on this occasion, blown to a distance of thirty feet in three seconds. In addition to the shivering of the spire, the pinnacles at the angles of the tower were all more or less damaged, the flying buttresses cracked through and violently shaken, many of the open battlements, at the base of the spire, knocked away, the roof of the Church completely riddled, the roofs of the side entrances destroyed, and the stone staircases of the gallery shattered."[1]

Lightning has been, at all times, the cause of great damage to property, by its power of setting fire to whatever is combustible. Fuller says, in his Church History, that "scarcely a great Abbey exists in England which once, at least, has not been burned by lightning from heaven." He mentions, as examples, the Abbey of Croyland twice burned, the Monastery of Canterbury twice, the Abbey of Peterborough twice; also the Abbey of St. Mary's, in Yorkshire, the Abbey of Norwich, and several others. Sir William Snow Harris, writing about twenty years ago, tells us that "the number of churches and church spires wholly or

[1] The Thunderstorm, by Charles Tomlinson, F. R. S., Third Edition, pp. 153–4.

partially destroyed by lightning is beyond all belief, and would be too tedious a detail to enter upon. Within a comparatively few years, in 1822 for instance, we find the magnificent Cathedral of Rouen burned, and so lately as 1850 the beautiful Cathedral of Saragossa, in Spain, struck by lightning, during Divine Service, and set on fire. In March of last year, a despatch from our Minister at Brussels, Lord Howard de Walden, dated the twenty-fourth of February, was forwarded by Lord Russell to the Royal Society, stating that, on the preceding Sunday, a violent thunderstorm had spread over Belgium, that twelve churches had been struck by lightning, and that three of these fine old buildings had been totally destroyed."[1]

Even in our own day, the destruction caused by fires, produced through the agency of Lightning, is very great; far greater than is commonly supposed. No general record of such fires is kept, and consequently our information on the subject is very incomplete and inexact. I may tell you, however, one small fact which, so far as it goes, is precise enough, and very significant. In the little Province of Schleswig-Holstein, which occupies an area less than one-fourth of the area of Ireland, the Provincial Fire Assurance Association has paid, in sixteen years, for damage caused by Lightning, somewhat over £100,000, or at the rate of more than £6,000 a-year. The total loss of property every year in this province, due to fires caused by Lightning, is estimated at not less than £12,500.[2]

[1] Two Lectures on Atmospheric Electricity and Protection from Lightning; published at the end of his Treatise on Frictional Electricity, p. 273.

[2] See Report of Lightning Rod Conference, p. 119.

Destruction of Ships at Sea.—The destructive effects of Lightning on ships at sea, before the general adoption of Lightning Conductors, seems almost incredible at the present day. From official records, it appears that the damage done to the Royal Navy of England alone involved an expenditure of from £6,000 to £10,000 a year. We are told by Sir William Snow Harris, who devoted himself for many years to this subject, with extraordinary zeal and complete success, that between the year 1810 and the year 1815, that is, within a period of five years, "No less than forty sail of the line, twenty frigates, and twelve sloops and corvettes, were placed *hors de combat* by Lightning. In the Merchant Navy, within a comparatively small number of years, no less than thirty-four ships, most of them large vessels with rich cargoes, have been totally destroyed—been either burned or sunk—to say nothing of a host of vessels partially destroyed or severely damaged."[1]

And these statements, be it observed, take no account of ships that were simply reported as missing, some of which, we can hardly doubt, were struck by Lightning in the open sea, and went down with all hands on board. A famous ship of fourty-four guns, the *Resistance*, was struck by Lightning in the Straits of Malacca, and the powder magazine exploding, she went to the bottom. Of her whole crew only three were saved, who happened to be picked up by a passing boat. It has been well observed that, were it not for these three chance survivors, nothing would have been known concerning the fate of the vessel, and she would have been simply recorded as missing, in the Admiralty lists.

[1] Loco citato.

Nothing is more fearful to contemplate than the scene on board a ship, when she is struck by Lightning in the open sea, with the winds howling around, the waves rolling mountains high, the rain coming down in torrents, and the vivid flashes lighting up the gloom at intervals, and carrying death and destruction in their track. I will read you one or two brief accounts of such a scene, given in the pithy but expressive language of the sailor. In January, 1786, the *Thisbe*, of thirty-six guns, was struck by Lightning, off the coast of Scilly, and reduced to the condition of a wreck. Here is an extract from the ship's log:—"Four A. M., strong gales; handed mainsail and main top-sail; hove to with storm stay-sails. Blowing very heavy, S. E. 4.15, a flash of lightning, with tremendous thunder, disabled some of our people. A second flash set the mainsail, main-top, and mizen stay-sails on fire. Obliged to cut away the mainmast; this carried away mizen top-mast and fore top-sail yard. Found fore-mast also shivered by the lightning. Fore top-mast went over the side about 9 A. M. Set the foresail." [1]

A few years later, in March, 1796, the *Lowestoffe* was struck in the Mediterranean, and we read as follows in the log of the ship:—"North end of Minorca; heavy squalls; hail, rain, thunder, and lightning. 12.15, ship struck by lightning, which knocked three men from the mast-head, one killed. 12.30, ship again struck. Main top-mast shivered in pieces; many men struck senseless on the decks. Ship again struck, and set on fire in the masts and rigging. Main-mast shivered in pieces; fore top-mast shivered; men benumbed on the decks, and knocked out of the top; one man

[1] Sir William Snow Harris, loco citato, p. 274.

killed on the spot. 1.30, cut away the mainmast; employed clearing wreck. 4, moderate; set the foresail." [1]

Again, in 1810, the *Repulse*, a ship of seventy-four guns, was struck, off the coast of Spain. "The wind had been variable in the morning, and at 12.35 there was a heavy squall, with rain, thunder, and lightning. The ship was struck by two vivid flashes of lightning, which shivered the maintop-gallant mast, and severely damaged the mainmast. Seven men were killed on the spot; three others only survived a few days; and ten others were maimed for life. After the second discharge the rain fell in torrents; the ship was more completely crippled than if she had been in action, and the squadron, then engaged on a critical service, lost for a time one of its fastest and best ships." [2]

Destruction of Powder Magazines.—Not less appalling is the devastation caused by Lightning, when it falls on a powder magazine. Here is a striking example. On the eighteenth of August, 1769, the tower of St. Nazaire, at Brescia, was struck by Lightning. Underneath the tower, about 200,000 pounds of gunpowder, belonging to the Republic of Venice, were stored in vaults. The powder exploded, levelling to the ground a great part of the beautiful city of Brescia, and burying thousands of its inhabitants in the ruins. It is said that the tower itself was blown up bodily to a great height in the air, and came down in a shower of stones.

This is, perhaps, the most fearful disaster of the kind on record. But we are not without examples in our own times. In the year 1856, the Lightning fell on the Church of St. John,

[1] Sir William Snow Harris, loco citato, p. 275.
[2] The Thunderstorm, by Charles Tomlinson, F.R.S., Third Edition, p. 172.

in the island of Rhodes. A large quantity of gunpowder had been deposited in the vaults of the Church. This was ignited by the flash; the building was reduced to a mass of ruins; a large portion of the town was destroyed; and a considerable number of the inhabitants were killed. Again, in the following year, the magazine of Joudpore, in the Bombay Presidency, was struck by Lightning. Many thousand pounds of gunpowder were blown up; five hundred houses were destroyed; and nearly a thousand people are said to have been killed.[1]

Experimental Illustrations.—And now, before proceeding further, I will make one or two experiments, with a view of showing that the electricity of our machines is capable of producing effects similar to those produced by Lightning, though immeasurably inferior in point of magnitude. Here is a common tumbler, about three-quarters full of water. Into it I introduce two bent rods of brass, which are carefully insulated, below the surface of the water, by a covering of india rubber. The points, however, are exposed, and come to within an inch of one another, near the bottom of the tumbler. Outside the tumbler, the brass rods are mounted on a stand, by means of which I can send the full charge of this Leyden Jar battery through the water, from point to point. Since water is a bad conductor of electricity, as compared with metals, the charge encounters great resistance in passing through it, and in overcoming this resistance, produces considerable mechanical commotion, which is usually sufficient to shiver the glass to pieces.

[1] See for these facts, Anderson, Lightning Conductors, p. 197; Tomlinson, The Thunderstorm, pp. 167–9; Harris, loco citato, pp. 273–4.

To charge the battery will take about twenty turns of this large Holtz machine. Observe how the pith ball of the electroscope rises as the machine is worked, showing that the charge is going in. And now it remains stationary; which is a sign that the battery is fully charged, and can receive no more. You will notice that the outside coating

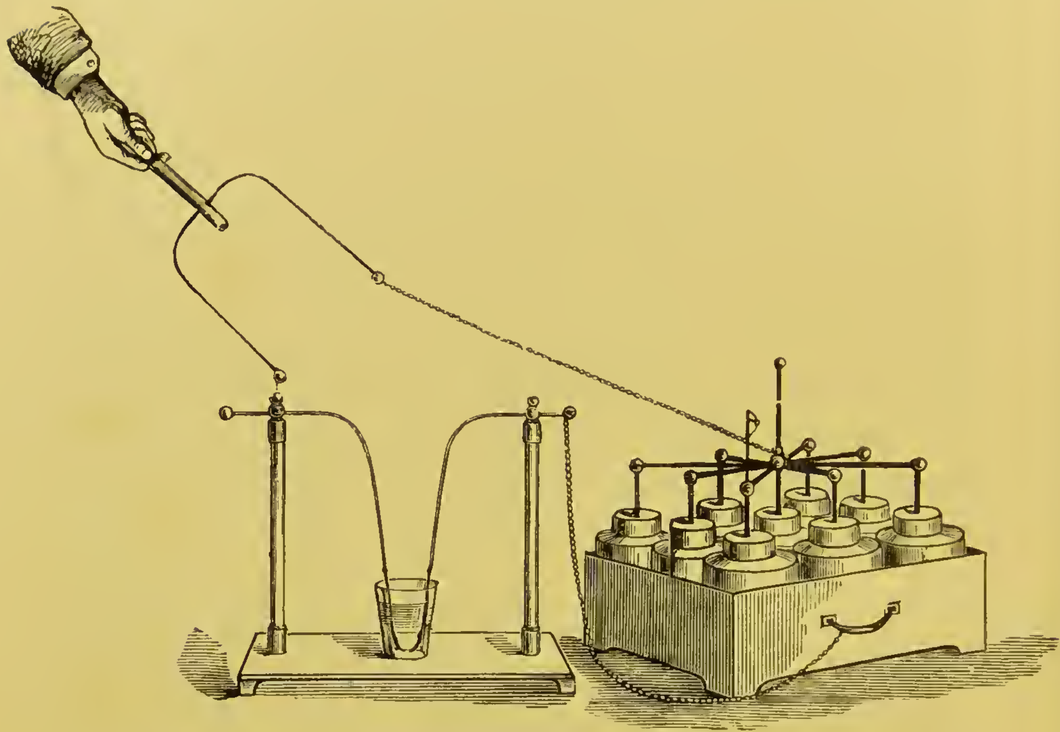

Fig. 16.

Glass Vessel broken by Discharge of Leyden Jar Battery.

of the battery has been already connected with one of the brass rods, dipping into the tumbler of water. By means of this discharger, I will now bring the inside coating into connexion with the other rod. And see, before contact is actually made, the spark has leaped across, and our tumbler is violently burst asunder from top to bottom.

This will probably appear to you a very small affair, when compared with the tearing asunder of solid masonry, and the hurling about of stones by the ton weight. No doubt it is: and that is just one of the lessons we have to learn from the experiment we have made. For, not only does it show us that effects of this kind may be caused by electricity artificially produced, but it brings home forcibly to the mind how incomparably more powerful is the Lightning of the clouds than the electricity of our machines.

The property which electricity has of setting fire to combustible substances may be easily illustrated. This india rubber tube is connected with the gas-pipe under the floor; and to the end of the tube is fitted a brass stop-cock which I hold in my hand. I open the cock, and allow the jet of gas to flow towards the conductor of Carré's machine, while my assistant turns the handle; a spark passes, and the gas is lit. Again, my assistant stands on this insulating stool, placing his hand on the large conductor of the machine, while I turn the handle. His body becomes electrified; and when he presents his knuckle to this vessel of spirits of wine, which is electrically connected with the earth, a spark leaps across, and the spirits of wine are at once in a blaze. Once more: I tie a little gun-cotton around one knob of the discharging rod, and then use it to discharge a small Leyden Jar; at the moment of the discharge the gun-cotton is set on fire.

It would be easy to explode gunpowder with the electric spark; but the smoke of the explosion would make the Lecture-hall very unpleasant for the remainder of the Lecture. I propose, therefore, to substitute for gunpowder

an explosive mixture of oxygen and hydrogen, with which I have filled this little metal flask, commonly known as Volta's pistol. By a very simple contrivance, the electric spark is discharged through the mixture, when I hold the flask towards the conductor of the machine. A cork is fitted tightly into the neck of the flask; and at the moment the spark passes you hear a loud explosion, and you see the cork driven violently up to the ceiling.

Destruction of Life.—The last effect of Lightning to which I shall refer, and which, perhaps, more than any other,

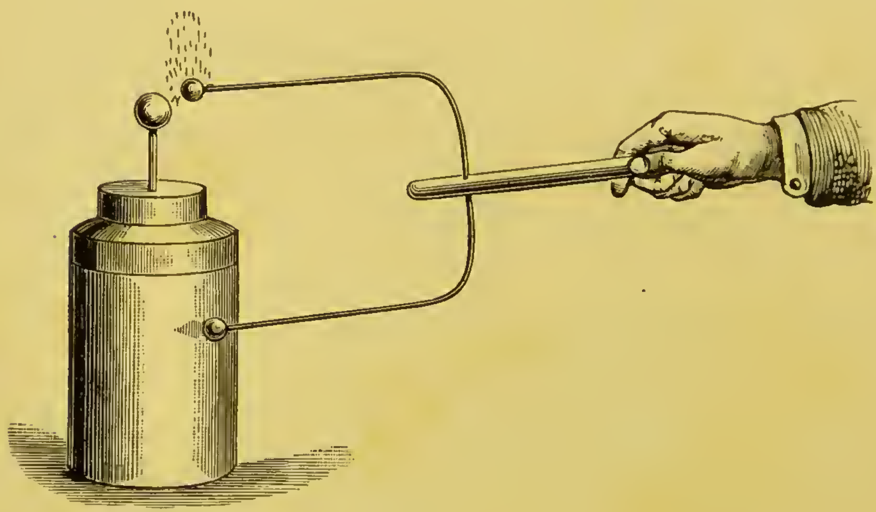

Fig. 17.

Gun-cotton set on Fire by Electric Spark.

strikes us with terror, is the sudden and utter extinction of life, when the Lightning flash descends on man or on beast. So swift is this effect, in most cases, that death is, in all probability, absolutely painless, and the victim is dead before he can feel that he is struck. I cannot give you, with any de-

gree of exactness, the number of people killed every year by Lightning; because the record of such deaths has been hitherto very imperfectly kept, in almost all countries, and is, beyond doubt, very incomplete. But perhaps you will be surprised to learn that the number of deaths by Lightning actually recorded is, on an average, in England about 22 every year, in France 80, in Prussia 110, in Austria 212, in European Russia 440.[1]

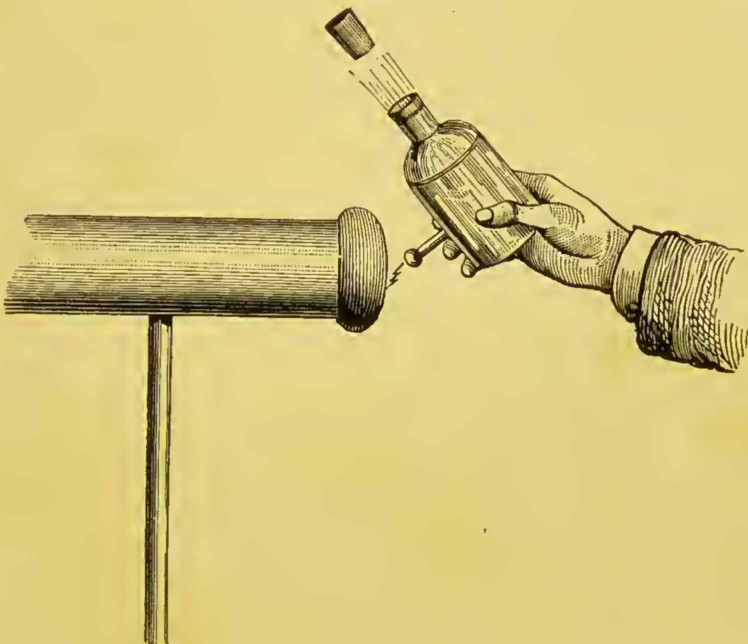

Fig. 18.

Volta's Pistol: Explosion caused by Electric Spark.

So far as can be gathered from the existing sources of information, it would seem that the number of persons killed by Lightning is, on the whole, about one in three of those who are struck. The rest are sometimes only stunned,

[1] See Anderson, Lightning Conductors, pp. 170–5.

sometimes more or less burned, sometimes made deaf for a time, sometimes partially paralyzed. On particular occasions, however, especially when the Lightning falls on a large assembly of people, the number of persons struck down and slightly injured, in proportion to the number killed, is very much increased.

An interesting case of this kind is reported by Mr. Tomlinson. "On the twenty-ninth of August, 1847, at the parish church of Welton, Lincolnshire, while the congregation were engaged in singing the hymn before the sermon, and the Rev. Mr. Williamson had just ascended the pulpit, the Lightning was seen to enter the church from the belfry, and instantly an explosion occurred in the centre of the edifice. All that could move made for the door, and Mr. Williamson descended from the pulpit, endeavouring to allay the fears of the people. But attention was now called to the fact that several of the congregation were lying in different parts of the church, apparently dead, some of whom had their clothing on fire. Five women were found injured, and having their faces blackened and burned; and a boy had his clothes almost entirely consumed. A respected old parishioner, Mr. Brownlow, aged sixty-eight, was discovered lying at the bottom of his pew, immediately beneath one of the chandeliers, quite dead. There were no marks on the body; but the buttons of his waistcoat were melted, the right leg of his trousers torn down, and his coat literally burnt off. His wife in the same pew received no injury." [1]

[1] The Thunderstorm, pp. 158–9. See also an account of four persons, who were struck on the Matterhorn, in July, 1869, all of whom were hurt, and none killed, Whymper's Scrambles amongst the Alps, pp. 414, 415.

Not less striking is the story told by Dr. Plummer, surgeon of the Illinois Volunteers, in the Medical and Surgical Reporter of June 19, 1865. "Our regiment was yesterday the scene of one of the most terrible calamities which it has been my lot to witness. About two o'clock a violent thunderstorm visited us. While the old guard was being turned out to receive the new, a blinding flash of lightning was seen, accompanied instantly by a terrific peal of thunder. The whole of the old guard, together with part of the new, were thrown violently to the earth. The shock was so severe and sudden that, in most cases, the rear rank men were thrown across the front rank men. One man was instantly killed, and thirty-two men were more or less severely burned by the electric fluid. In some instances the men's boots and shoes were rent from their feet and torn to pieces, and, strange as it may appear, the men were injured but little in the feet. In all cases the burns appear as if they had been caused by scalding-hot water, in many instances the skin being shrivelled and torn off. The men all seem to be doing well, and a part of them will be able to resume their duties in a few days."

The Return Shock.—It sometimes happens that people are struck down, and even killed, at the moment a discharge of Lightning takes place between a cloud and the earth, though they are very far from the point where the flash is actually seen to pass; while others, who are situated between them and the Lightning, suffer very little, or perhaps not at all. This curious phenomenon was first carefully investigated by Lord Mahon, in the year 1779, and was called by him the Return Shock. His theory, which is now commonly

accepted, may be easily understood, with the aid of the sketch before you.

Let us suppose ABC to represent the outline of a Thundercloud, which dips down towards the earth at A and at C. The electricity of the cloud develops, by inductive action, a charge of the opposite kind in the earth beneath it.

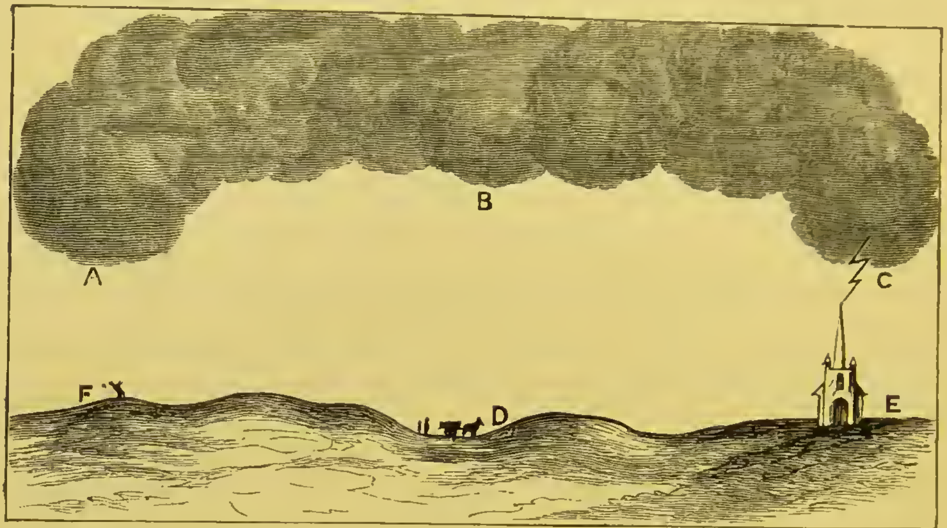

FIG. 19.

THE RETURN SHOCK ILLUSTRATED.

But the inductive action is most powerful at E and F, where the cloud comes nearest to the earth. Hence bodies situated near these points may be very highly electrified, as compared with bodies at a point between them, such as D. Now when a flash of Lightning passes at E, the under part of the cloud is at once relieved of its electricity; its inductive action ceases; and therefore a person situated at F suddenly ceases to be electrified. This sudden change, from a highly electrified to a neutral state, involves a shock to his system, which may be severe enough to stun, or even to kill him. Mean-

while, people at D, having been also electrified, to some extent, by the influence of the Thundercloud, must, in like manner, undergo a change in their electrical condition when the flash of Lightning passes: but this change will be less violent, because they were less highly electrified.

Many experiments have been devised to illustrate this theory of Lord Mahon. But the best illustration I know is furnished by this electric machine of Carré's. If you stand near one end of the large conductor, when the machine is in action, and sparks are taken from the other end, you will feel a distinct electric shock every time a spark passes. The large conductor here takes the place of the cloud; the spark that passes, at one end, represents the flash of Lightning; and the observer, at the other end, gets the Return Shock, though he is at a considerable distance from the point where the flash is seen.

An experiment of this kind, of course, cannot be made sensible to a large audience like the present. But I can give you a good idea of the effect, by means of this tuft of coloured papers. While the machine is in action, I hold the tuft of papers near that end of the conductor which is farthest from the point where the discharge takes place. You see the paper ribbons are electrified by induction, and, in virtue of mutual repulsion, stand out from one another, "like quills upon the fretful porcupine." But when a spark passes, the inductive action ceases; the paper ribbons cease to be electrified; and the whole tuft suddenly collapses into its normal state.

While fully accepting Lord Mahon's theory of the Return Shock as perfectly good, so far as it goes, I would venture

to point out another influence, which must often contribute largely to produce the effect in question, and which is not dependent on the form of the cloud. It may easily happen, from the nature of the surface in the district affected by a Thundercloud, that the point of most intense electrification, say E in the figure, is in good electrical communication with a distant point, such as F, while it is very imperfectly connected with a much nearer point, D. In such a case, it is evident that bodies at F will share largely in the highly electrified condition of E, and also share largely in the sudden change of that condition, the moment the flash of Lightning passes: whereas, bodies at D will be less highly electrified before the discharge, and less violently disturbed when the discharge takes place.

This principle may be illustrated by a very simple experiment. Here is a brass chain about twenty feet long. One end of it I hand to any one amongst the audience who will kindly take hold of it: the other end I hold in my hand. I now stand near the conductor of the machine; and will ask some one to stand about ten feet away from me, near the middle of the chain, but without touching it. Now, observe what happens when the machine is worked, and I take a spark from the conductor. My friend at the far end of the chain, twenty feet away, gets a shock nearly as severe as the one I get myself; because he is in good electrical communication with the point where the discharge takes place. But my more fortunate friend, who is ten feet nearer to the flash, is hardly sensible of any effect; because he is connected with me only through the floor of the hall, which is, comparatively speaking, a bad conductor of electricity.

Summary.—Let me now briefly sum up the chief destructive effects of Lightning. First, with regard to good conductors: though it passes harmlessly through them if they be large enough to afford it an easy passage, it melts and converts them into vapour if they be of such small dimensions as to offer considerable resistance. Secondly, Lightning acts with great mechanical force on bad conductors; it is capable of tearing asunder large masses of masonry, and of projecting the fragments to a considerable distance. Thirdly, it sets fire to combustible materials. And lastly, it causes the instantaneous death of men and animals.

Franklin's Lightning Rods.—The object of Lightning Conductors is to protect life and property from these destructive effects. Their use was first suggested by Franklin, in 1749, even before his famous experiment with the kite: and immediately after that experiment in 1752, he set up, on his own house in Philadelphia, the first Lightning Conductor ever made. He even devised an ingenious contrivance, by means of which he received notice when a Thundercloud was approaching. The contrivance consisted of a peal of bells, which he hung on his Lightning Conductor, and which were set ringing whenever the Lightning Conductor became charged with electricity.

Franklin's Lightning Rods were soon adopted in America; and he himself contributed very much to their popularity by the simple and lucid instructions he issued every year, for the benefit of his countrymen, in the annual publication known as Poor Richard's Almanac. It is very interesting, at this distance of time, to read the homely practical rules laid down by this great philosopher and statesman; and, though some

modifications have been suggested by the experience of a hundred and thirty years, especially as regards the dimensions of the Lightning Conductor, it is surprising to find how accurately the general principles of its construction, and of its action, are here set forth.

"It has pleased God," he says, "in His goodness to mankind, at length to discover to them the means of securing their habitations, and other buildings, from mischief by thunder and lightning. The method is this:—Provide a small iron rod, which may be made of the rod-iron used by nailors, but of such a length that one end being three or four feet in the moist ground, the other may be six or eight feet above the highest part of the building. To the upper end of the rod fasten about a foot of brass wire, the size of a common knitting needle, sharpened to a fine point: the rod may be secured on the house by a few small staples. If the house or barn be long, there may be a rod and point at each end, and a middling wire along the ridge from one to the other. A house thus furnished will not be damaged by lightning, it being attracted by the points and passing through the metal, into the ground, without hurting anything. Vessels also having a sharp-pointed rod fixed on the top of their masts, with a wire from the foot of the rod reaching down round one of the shrouds to the water, will not be hurt by lightning."

Introduction of Lightning Rods into England.—The progress of Lightning Conductors was more slow in England, and on the Continent of Europe, owing to a fear, not unnatural, that they might, in some cases, draw down the Lightning where it would not otherwise have fallen. People

preferred to take their chance of escaping as they had escaped before, rather than invite, as it were, the Lightning to descend on their houses, in the hope that an iron rod would convey it harmless to the earth. But the immense amount of damage done, every year, by Lightning, soon led practical men to entertain a proposal which offered complete immunity from all danger, on such easy terms; and when it was found that buildings protected by Lightning Conductors were, over and over again, struck by Lightning without suffering any harm, a general conviction of their utility was gradually established in the public mind.

The first public building protected by a Lightning Rod, in England, was St. Paul's Cathedral, in London. On the eighteenth of June, 1764, the beautiful steeple of Saint Bride's Church, in the City, was struck by Lightning, and reduced to ruin. This incident awakened the attention of the Dean and Chapter of St. Paul's to the danger of a similar calamity, which seemed, as it were, impending over their own church. After long deliberation, they referred the matter to the Royal Society, asking for advice and instruction. A committee of scientific men was appointed by the Royal Society to consider the question. Benjamin Franklin himself, who happened to be in London at the time, as the representative of the American States in their dispute with England, was nominated a member of the committee. And the result of its deliberation was that, in the year 1769, a number of Lightning Conductors were erected on St. Paul's Cathedral.

It was on this occasion that arose the celebrated controversy about the respective merits of points and balls. Franklin

had recommended a pointed conductor; but some members of the committee were of opinion that the conductor should end in a ball and not in a point. The decision of the committee was in favour of Franklin's opinion; and pointed conductors were accordingly adopted for St. Paul's Cathedral. But the controversy did not end here. The time was one of great political excitement, and party spirit infused itself even into the peaceful discussions of science. The weight of scientific opinion was on the side of Franklin; but it was hinted, on the other side, that the pointed conductors were tainted with republicanism, and pregnant with danger to the empire. As a rule, the Whigs were strongly in favour of points; while the Tories were enthusiastic in their support of balls.

For a time the Tories seemed to prevail. The king was on their side. Experiments on a grand scale were conducted, in his presence, at the Pantheon, a large building in Oxford-street: he was assured that these experiments proved the great superiority of balls over points; and to give practical effect to his convictions, his Majesty directed that a large cannon ball should be fixed on the end of the Lightning Conductor attached to the Royal Palace at Kew. But the committee of the Royal Society remained unconvinced. In course of time the heat of party spirit abated: experience as well as reason was found to be in favour of Franklin's views: and the battle of the balls and points has long since passed into the domain of history.[1]

Functions of a Lightning Conductor.—A Lightning Con-

[1] See Philosophical Transactions of the Royal Society, 1773, p. 42, and 1778, part i. p. 232; Anderson's Lightning Conductors, pp. 40–2; Lightning Rod Conference, pp. 76–9.

ductor fulfils two functions. First, it favours a silent and gradual discharge of electricity between the cloud and the earth, and thus tends to prevent that accumulation which must of necessity take place, before a flash of Lightning will pass. Secondly, if the flash of Lightning come, the Lightning Conductor offers it a safe channel, through which it may pass harmless to the earth.

These two functions of a Lightning Conductor may be easily illustrated by experiment. When our machine is in action, if I present my closed hand to the large brass conductor, a spark passes between them, and I feel, at the same moment, a slight electric shock. Here the conductor of the machine, as usual, holds the place of the electrified cloud; my closed hand represents, as it were, a lofty building that stands out prominently on the surface of the earth; the spark is the flash of Lightning; and the electric shock just suggests the destructive power of the sudden disruptive discharge.

Now let me protect this building by a Lightning Conductor. For this purpose, I take in my hand a brass rod, which I connect with the earth by a brass chain. In the first instance, I will have a metal ball on the end of my Lightning Conductor. You see the effect: sparks pass rapidly, but I feel no shock. I can increase the strength of the discharge by hanging this condensing jar on the conductor of the machine. Sparks pass now, much more brilliant and powerful than before, but still I get no shock. It is evident, therefore, that my Lightning Rod does not prevent the flash from passing, but it conveys it harmless to the ground.

I next take a rod which is sharply pointed, and connecting it as before with the earth, by a brass chain, I present the sharp point to the conductor of the machine. Observe how different is the result: there is no disruptive discharge; no spark passes; no shock is felt. Electricity still continues to be generated in the machine; and electricity is generated, by induction, in the brass rod, and in my body. But these two opposite electricities discharge themselves silently, by means of this pointed rod, and no sensible effect of any kind is exhibited.

These experiments are very simple; but they really put before us, in the clearest possible way, the whole theory of Lightning Conductors. In particular, they give us ocular demonstration that an efficient Lightning Rod not only makes the Lightning harmless, when it comes, but tends very much to prevent its coming. A remarkable example, on a large scale, of this important property, is furnished by the town of Pietermaritzburg, the capital of the colony of Natal, in South Africa. This town is subject to the frequent visitation of Thunderstorms, at certain seasons of the year, and much damage was formerly done by Lightning; but since the erection of Lightning Conductors on the principal buildings, the Lightning has never fallen within the town. Thunderclouds come as before: but they pass silently over the city; and only begin to emit their Lightning flashes when they reach the open country, and have passed beyond the range of the Lightning Conductors.[1]

But it will often happen, even in the case of a pointed

[1] See A Lecture on Thunderstorms, by Professor Tait of Edinburgh, published in Nature, vol. xxii., p. 365.

Conductor, that the accumulation of electricity goes on so fast that the silent discharge is insufficient to keep it in check. A disruptive discharge will then take place, from time to time, and a flash of Lightning will pass. Under these circumstances, the Lightning Conductor is called upon to fulfil its second function, and to convey the Lightning harmless to the earth.

Conditions of a Lightning Conductor.—From the consideration of the functions which it has to fulfil, we may now infer what are the conditions necessary for an efficient Lightning Conductor. The first condition is that the end of the Conductor, projecting into the air, should have, at least, one sharp point. Our experiments have shown us that a pointed Conductor tends, in a manner, to suppress the flash of Lightning altogether; whereas a blunt Conductor, or one ending in a ball, tends only to make it harmless when it comes. It is evident, therefore, that the pointed Conductor offers the greater security.

But a fine point is very liable to be melted when the Lightning falls upon it, and thus to be rendered less efficient for future service. To meet this danger, it has recently been suggested, by the Lightning Rod Conference, that the extreme end of the Conductor should be a blunt point, destined to receive the full force of the Lightning flash, when it comes; and that, a little lower down, a number of very fine points should be provided, with a view to favour the silent discharge. This suggestion, which appears admirably fitted to provide for the twofold function of a Lightning Conductor, deserves to be recorded in the exact terms of the Official Report.

"It seems best to separate the double functions of the point, prolonging the upper terminal to the very summit, and merely bevelling it off, so that, if a disruptive discharge does take place, the full conducting power of the Rod may be ready to receive it. At the same time, having regard to the importance of silent discharge from sharp points, we suggest that, at one foot below the extreme top of the upper terminal, there be firmly attached, by screws and solder, a copper ring bearing three or four copper needles, each six inches long, and tapering from a quarter of an inch diameter to as fine a point as can be made; and with the object of rendering the sharpness as permanent as possible, we advise that they be platinized, gilded, or nickel plated."[1]

The second condition of a Lightning Conductor is, that it should be made of such material, and of such dimensions, as to offer an easy passage to the greatest flash of Lightning likely to fall on it: otherwise it might be melted by the discharge, and the Lightning, seeking for itself another path, might force its way through bad Conductors, which it would partly rend asunder, and partly consume by fire. Copper is now generally regarded as the best material for Lightning Conductors, and it is almost universally employed in these countries. If it is used in the form of a rope, it should not be less than half an inch in diameter: if a band of copper is preferred—and it is often found more convenient by builders—it should be about an inch and a half broad and an eighth of an inch thick. In France it has been hitherto more usual to employ iron rods for Lightning Conductors: but since

[1] Report of the Lightning Rod Conference, p. 4.

iron is much inferior to copper, in its conducting power, the iron rod must be of much larger dimensions; it should be, at least, one inch in diameter.[1]

The third condition is, that the Lightning Conductor should be continuous throughout its whole length, and should be placed in good electrical contact with the earth. This is a condition of the first importance; and experience has shown that it is the one most likely of all to be neglected. In a large town, the best earth connexion is furnished by the system of water-mains and gas-mains, each of which constitutes a great network of conductors, everywhere in contact with the earth. Two points, however, must be carefully attended to: first, that the electrical contact between the Lightning Conductor and the metal pipe should be absolutely perfect; and, secondly, that the pipe selected should be of such large dimensions as to allow the Lightning an easy passage through it to the principal main.

If no such system of water-pipes or gas-pipes is at hand, then the Lightning Rod should be connected with moist earth, by means of a bed of charcoal, or a metal plate not less than three feet square. This metal plate should be always of the same material as the Conductor: otherwise

[1] The dimensions here set forth are greater, in some respects, than those "recommended as a minimum" in the Report of the Lightning Rod Conference, page 6. But it will be observed by those who consult the Report, that the minimum recommended is just the size which, in the preceding paragraph of the Report, is said to have been actually melted by a flash of Lightning; and therefore it seems not to be a very safe minimum. It will be also seen that there is some confusion in the figures given, and that they contradict one another. For the dimensions of iron rods, see the Instructions adopted by the Academy of Science, Paris, May 20, 1875; Lightning Rod Conference, pp. 67–8.

a galvanic action would be set up between the two metals, which, in course of time, might seriously damage the contact. Dry earth, sand, rock, and shingle, are bad conductors; and, if such materials exist near the surface of the earth, the Lightning Rod must pass through them, and be carried down until it reaches water, or permanently damp earth.

Mischief done by bad Conductors.—If the earth contact is bad, a Lightning Conductor does more harm than good. It invites the Lightning down upon the building, without providing for it, at the same time, a free passage to earth. The consequence is that the Lightning forces a way for itself, violently bursting asunder whatever opposes its progress, and setting fire to whatever is combustible.

I will give you some recent and striking examples. In the month of May, 1879, the Church of Laughton-en-le-Morthen, in England, though provided with a Conductor, was struck by Lightning, and sustained considerable damage. On examination, it was found that the Lightning followed the Conductor down along the spire as far as the roof; then, changing its course, it forced its way through a buttress of massive masonwork, dislodging about two cartloads of stones, and leaped over to the leads of the roof, about six feet distant; it now followed the leads until it came to the cast-iron downpipes intended to discharge the rain water; and through these it descended to the earth. When the earth contact of the Lightning Conductor was examined, it was found exceedingly deficient. The Rod was simply bent underground, and buried in dry loose rubbish, at a depth not exceeding eighteen inches. This is a very instructive

example. The Lightning had a choice of two paths, one by the Conductor prepared for it, the other by the leads of the roof and the downpipes: and by a kind of instinct, which, however we may explain, we must always contemplate with wonder, it chose the path of least resistance; though in doing so it had to burst its way, at the outset, through a massive wall of solid masonry.[1]

On the fifth of June in the same year, a flash of Lightning struck the house of Mr. Osbaldiston, near Sheffield, and notwithstanding the supposed protection of a Lightning Conductor, it did damage to the amount of about five hundred pounds. The Lightning here followed the Conductor, to a point about nine feet from the ground, then passed through a thick wall to a gas-pipe, at the back of the drawingroom mirror. It melted the gas-pipe, set fire to the gas, smashed the mirror to atoms, broke the Sevres vases on the chimney-piece, and dashed the furniture about. In this case, as in the former, it was found that the earth contact was bad; and, in addition, the Conductor itself was of too small dimensions. Hence the electric discharge found an easier path to earth through the gas-pipes, though to reach them it had to force for itself a passage through a resisting mass of non-conductors.[2]

Again, in the same year, on the twenty-eighth of May, the house of Mr. Tomes, of Caterham, was struck by Lightning, and some slight damage was done. After a careful examination, it was found that the greater part of the

[1] See Letter of Mr. R. S. Newall, F.R.S., in The Times, May 30, 1879.

[2] See Nature, June 12, 1879, vol. xx. p. 146.

discharge left the Lightning Conductor, with which the house was provided, and passed over the slope of the roof to an attic room, into which it forced its way through a brick wall, and reached a small iron cistern. This cistern was connected by an iron pipe, of considerable dimensions, with two pumps in the basement story; and through them the Lightning found an easy passage to the earth, and did but little harm on its way. When the earth contact of the Lightning Conductor was examined, it was discovered that the end of the Rod was simply stuck into a dry chalky soil, to a depth of about twelve inches Thus, in this case, as in the two former, it was made quite clear that the Lightning Conductor failed to fulfil its functions, because the earth contact was bad.[1]

Cases are not uncommon in which builders provide underground a carefully constructed reservoir of water, into which the lower end of the Lightning Rod is introduced. The idea seems to prevail that a reservoir of water constitutes a good earth contact; and this is quite true of a natural reservoir, such as a lake, where the water is in contact with moist earth, over a considerable area. But an artificial reservoir may have quite an opposite character, and practically insulate the Lightning Conductor from the earth. One which came under my notice lately, in the neighbourhood of this city, consists of a large earthenware pipe, set on end in a bed of cement, and kept half full of water. Now, the earthenware pipe is a good insulator, and so is the bed of cement in which it rests: and the whole arrangement is identical, in all essential

[2] See Letter of Mr. Tomes in Nature, vol. xx. p. 145; also Lightning Rod Conference, pp. 210–15.

features, with the apparatus of Professor Richman, in which he introduced his Lightning Rod into a glass bottle, and by which he lost his life a hundred and thirty years ago.

A Conductor mounted in this manner will, probably enough, draw down Lightning from the clouds; but it is more likely to discharge it, with destructive effect, into the building it is intended to guard, than to transmit it harmlessly to the earth. An example is at hand in the case of Christ Church, in the town of Clevedon, in Somersetshire. This Church was provided with a very efficient system of Lightning Conductors, five in number, corresponding to the four pinnacles and the flagstaff, on the summit of the principal tower. The five conductors consisted of good copper-wire rope; all were united together inside the tower, through which they were carried down to earth, and there ended in an earthenware drain. This kind of earth contact might be pretty good as long as water was flowing in the drain: but whenever the drain was dry, the Conductor was practically insulated from the earth. On the fifteenth of March, 1876, the church was struck by Lightning, which, for some distance, followed the line of the Conductor; then finding its passage barred by the earthenware drain, which was dry at the time, it burst through the walls of the church, displacing several hundred weight of stone, and making its way to earth through the gas-pipe.[1]

Another very instructive example is furnished by the Lightning Conductor attached to the Lighthouse of Berehaven, on the South-west Coast of Ireland. It consists of a

[1] See Anderson, Lightning Conductors, pp. 208–10.

half-inch copper-wire rope, which is carried down the face of the tower "until it reaches the rock at its base, where it terminates in *a small hole, three inches by three inches, jumped out of the rock, about six inches under the surface.*" Here, again, we have a good imitation of Professor Richman's experiment, with only this difference, that a small hole in the rock is substituted for a glass bottle. A Lightning Conductor, of this kind, fulfils two functions: it increases the chance of the Lightning coming down on the building; and it makes it positively certain that, having come, it cannot get to earth without doing mischief.

The Lightning did come down on the Berehaven Lighthouse, about five years ago. As might have been expected, it made no use of the Lightning Conductor in finding a path to earth, but forced its way through the building, dealing destruction around, as it descended from stage to stage. The Board of Irish Lights furnished a detailed report of this accident, to the Lightning Rod Conference, in March, 1880, from which the above particulars have been derived.[1]

Precaution against Rival Conductors.—But it is not enough to provide a good Lightning Conductor, which is itself able to convey the electric discharge harmless to the earth: we must take care that there are no rival Conductors, near at hand in the building, to draw off the Lightning from the path prepared for it, and conduct it by another route, in which its course might be marked with destruction. This precaution is of especial importance at the present day, owing

[1] See Lightning Rod Conference, pp. 208–10; see also the note at the end of this Lecture, p. 138.

to the great extent to which metal, of various kinds, is employed in the construction and fittings of modern buildings. I will take a typical case, which will bring home this point clearly to your minds.

A great part of the roof of many large buildings is covered with lead. The lead, at one or more points, may come near the gutters intended to collect the rain water: the gutters are in connection with the cast-iron down-pipes into which the water flows, and these down-pipes often pass into the earth, which, under the circumstances, is generally moist, and, therefore, in good electrical contact with the metal pipes. Here, then, is an irregular line of conductors which, though it has gaps, here and there, may, under certain conditions, offer to the Lightning discharge a path not less free than the Lightning Conductor itself. What is the consequence? The flash of Lightning, or a part of it, will quit the Lightning Rod, and make its way to earth through the broken series of conductors, doing, perhaps, serious mischief, as it leaps across, or bursts asunder, the non-conducting links in the chain.

Another illustration may be taken from the gas and water-pipes, with which almost all buildings in great cities are now provided, and which constitute a network of conductors, spreading out over the walls and ceilings, and stretching down into the earth, with which they have the best possible electrical contact. Now it often happens that a Lightning Conductor, at some point in its course, comes within a short distance of this network of pipes. In such a case, a portion of the electrical discharge is apt to leave the Lightning Conductor, force its way destructively through

masses of masonry, enter the network of pipes, melt the leaden gas-pipe, ignite the gas, and set the building on fire.

These are not merely the speculations of philosophers. All the various incidents I have just described have occurred, over and over again, during the last few years. You will remember, in some of the examples I have already set before you, when the electric discharge failed to find a sufficient path to earth through the Lightning Rod, it followed some such broken series of chance conductors as we are now considering. But this broken series of conductors seems to bring with it a special danger of its own, even when the Lightning Conductor is otherwise in efficient working order. I will give you just one case in point.

On the fifth of June, 1879, the Church of Sainte Marie, Rugby, was struck by Lightning, and set on fire, and narrowly escaped being burned to the ground. A number of workmen were engaged, on that day, in repairing the spire of the Church. About three o'clock they saw a dense black cloud approaching, and they came down to take shelter within the building. In a few minutes they heard a terrific crash, just overhead: at the same moment the gas was lighted under the organ loft, and the woodwork was set in a blaze. The men soon succeeded in putting out the fire, and the church escaped with very little damage.

Now, in this case, there was no reason to suppose that the Lightning Conductor was in any way defective. But about half-way up the spire there was a peal of eight bells. Attached to these bells were iron wires, about the eighth of an inch in diameter, leading from the clappers down to the organ loft, where they came within a short distance of a gas-

pipe fixed in the wall. It would seem that a great part of the discharge was carried safely to earth by the Lightning Conductor. But a part branched off at the bells in the spire, descended by the iron wires, and forced its way into the organ loft, to reach the network of gas-pipes, through which it passed down to the earth, melting the soft leaden gas-pipe in its course, and lighting the gas.

The remedy for this danger is obvious. All large masses of metal used in the structure of a building—the leads and gutters of the roof, the cast-iron down-pipes, the iron gas and water mains—should be put in good metallic connection with the Lightning Conductor, and, as far as may be, with one another. Connected in this way they furnish a continuous and effective line of conductors, leading safely down to earth, and instead of being a dangerous rival, they become a useful auxiliary to the Lightning Rod.

I would observe, however, that the Lightning Conductor ought not to be connected directly with the soft leaden pipes which are commonly employed to convey gas and water to the several parts of a building. Such pipes, as we have seen, are liable to be melted when any considerable part of the Lightning discharge passes through them; and thus much harm might be done, and the building might even be set on fire, by the lighting of the gas. Every good end will be attained, if the Conductor is put in metallic connection with the iron gas and water *mains*, either inside or outside the building.

Insulation of Lightning Conductors.—It is a question often asked, whether a Lightning Rod should be insulated from the building it is intended to protect. I believe that

this practice was formerly recommended by some writers; and I have observed that glass insulators are still employed, not unfrequently, by builders, in the erection of Lightning Conductors. But, from the principles I have set before you to-day, it seems clear that any insulation of this kind is, to say the least, altogether useless. The building to be protected is itself in electrical communication with the earth; and the Lightning Conductor, if efficient, is also in electrical communication with the earth. Therefore the Lightning Conductor and the building are in electrical communication with each other, through the earth; and any attempt at insulating them from one another, above the earth, is only labour thrown away.

Further, I have just shown you that the masses of metal employed in the structure or decoration of a building ought to be electrically connected with each other, and with the Lightning Conductor. Now if this be done, the Lightning Conductor is, by the fact, in direct communication with the building, and the glass insulators are utterly futile. Again, the building itself, during a Thunderstorm, becomes highly electrified by the inductive action of the cloud, and needs to be discharged, through the Conductor, just as the surrounding earth needs to be discharged. Therefore the more thoroughly it is connected with the Conductor, the more effectively will the Conductor fulfil its functions.

Personal Safety in a Thunderstorm.—I suppose there is hardly anyone to whom the question has not occurred, at some time or another, what he had best do to secure his personal safety during a Thunderstorm. This question is of so much practical interest that I think I shall be excused if I

say a few words about it, though perhaps, strictly speaking, it is somewhat beside the subject of Lightning Conductors.

At the outset, perhaps I shall surprise you when I say that you would enjoy the most perfect security if you were in a chamber entirely composed of metal plates, or in a cage constructed of metal bars, or if you were encased, like the knights of old, in a complete suit of metal armour. This kind of defence is looked upon as so perfect, among scientific men, that Professor Tait does not hesitate to recommend his adventurous young friends, devoted to the cause of science, to provide themselves with a light suit of copper, and thus protected, take the first opportunity of plunging into a Thundercloud, there to investigate, at its source, the process by which Lightning is manufactured.[1]

The reason why a metal covering affords complete protection is that, when a conductor is electrified, the whole charge of electricity exists on the outside surface of the conductor; and therefore, when a discharge takes place, it is only the outside surface that is affected. Thus if you were completely encased in a metal covering, and then charged with electricity by the inductive action of a Thundercloud, it is only the metal covering that would undergo any change of electrical condition; and when the Lightning flash would pass, it is only the metal covering that would be discharged.

Let me show you a very pretty and interesting experiment, to illustrate this principle. Here is a hollow brass

[1] Lecture on Thunderstorms, Nature, vol. xxii. pp. 365, 437. See also a very interesting Paper by the late Professor J. Clerk Maxwell, read before the British Association at Glasgow, in 1876, and reprinted in the Report of the Lightning Rod Conference, pp. 109, 110.

cylinder, open at the ends, mounted on an insulating stand. On the outside is erected a light brass rod, with two pith balls suspended from it by linen threads. Two pith balls are also

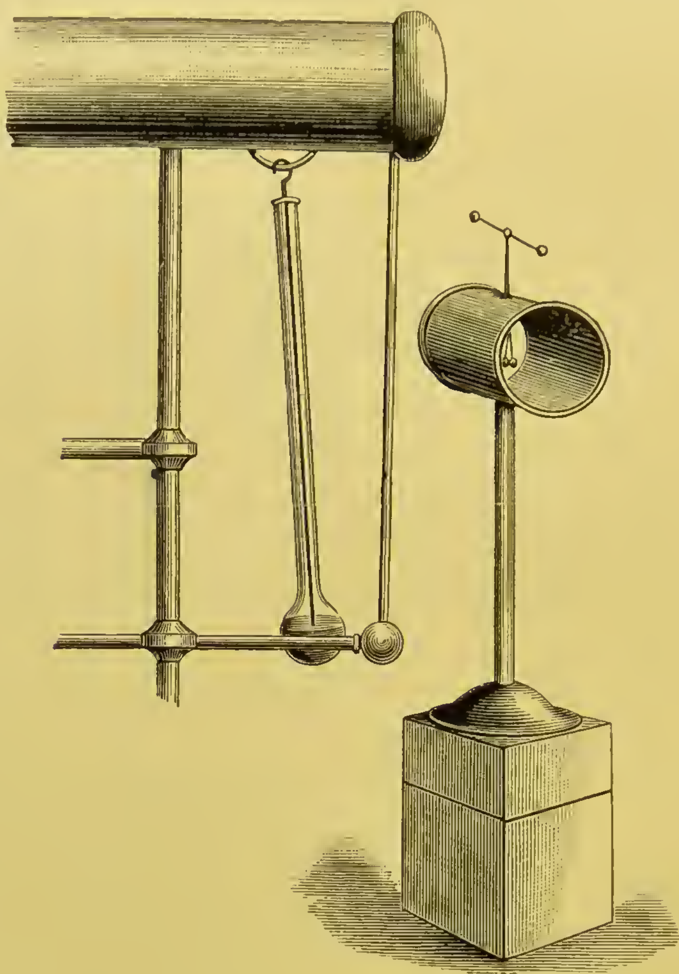

Fig. 20.

Protection from Lightning furnished by a Closed Conductor.

suspended, by linen threads, from the inner surface of the cylinder. You know that these pith balls will indicate to us the electrical condition of the surfaces to which they are attached. If the surface be electrified, the pith balls attached

to it will share in its electrical condition, and will repel each other: if the surface be neutral, the pith balls attached to it will be neutral, and will remain at rest.

I now put this apparatus under the influence of our Thundercloud, that is, the large brass conductor of our machine. The moment my assistant turns the handle, the electricity begins to be developed on the conductor, and you see, at once, the effect on the brass cylinder. The pith balls attached to the outer surface fly asunder: those attached to the inner surface remain at rest. And now a spark passes: our Thundercloud is discharged; the inductive action ceases; the pith balls on the outside suddenly collapse, while those on the inside are in no way affected.

It is not necessary that the brass cylinder should be insulated. To vary the experiment, I will now connect it with the earth by a chain; you will observe that the effect is precisely the same as before. Flash after flash passes while the machine continues in action; the outside pith balls fly about violently, being charged and discharged alternately; the inside pith balls remain all the time at rest. Thus you see clearly that, if you were sitting inside such a metal chamber as this, or covered with a complete suit of metal armour, you would be perfectly secure during a Thunderstorm, whether the chamber were electrically connected with the earth or insulated from it.

Practical Rules.—But it rarely happens, when a Thunderstorm comes, that an iron hut or a complete suit of armour is at hand, and you will naturally ask me what you ought to do under ordinary circumstances. First, let me tell you what you ought not to do. You ought not to

take shelter under a tree, or under a haystack, or under the lee of a house; you ought not to stand on the bank of a river, or close to a large sheet of water. If indoors, you ought not to stay near the fireplace, or near any of the flues or chimneys; you ought not to stand under a gasalier hanging from the ceiling; you ought not to remain close to the gas-pipes or water-pipes, or any large masses of metal, whether used in the construction of the building, or lying loosely about.

The necessity for these precautions is sufficiently evident from the principles I have already put before you. You want to prevent your body from becoming a link in that broken chain of conductors which, as we have seen, the electric discharge between earth and cloud is likely to follow. Now a tree is a better conductor than the air; and your body is a better conductor than a tree. Hence the Lightning, in choosing the path of least resistance, would leave the air to pass through the tree, and would leave the tree to pass through you. A like danger would await you if you stood under the lee of a haystack or of a house.

The number of people who lose their lives by taking refuge under trees in Thunderstorms is very remarkable. As one instance out of many, I may cite the following case, which was reported in The Times, July 14, 1887. "Yesterday the funeral of a negress was being conducted in a graveyard at Mount Pleasant, sixty miles north of Nashville, Tennessee, when a storm came on, and the crowd ran for shelter under the trees. Nine persons stood under a large oak, which the Lightning struck, killing everyone,

including three clergymen, and the mother and two sisters of the girl who had been buried."

Again, every large sheet of water constitutes practically a great conductor, which offers a very perfect medium of discharge between the earth round about and the cloud. Therefore, when a Thundercloud is overhead, the sheet of water is likely to become one end of the line of the Lightning discharge; and if you be standing near it, the line of discharge may pass through your body.

When Lightning strikes a building, it is very apt to use the stack of chimneys in making its way to earth; partly because the stack of chimneys is generally the most prominent part of the building, and partly because, on account of the heated air and the soot within the chimney, it is usually a moderately good conductor. Therefore, if you be indoors, you must keep well away from the chimneys; and for a similar reason, you must keep as far as you can from large masses of metal of every kind.

Having pointed out the sources of danger which you must try to avoid in a Thunderstorm, I have nearly exhausted all the practical advice that I have at my command. But there are some occasions on which it may be possible, not only to avoid evident sources of danger, but to make special provision for your own security. Thus, for example, in the open country, if you stand a short distance from a wood, you may consider yourself as practically protected by a Lightning Conductor. For a wood, by its numerous branches and leaves, favours very much a quiet discharge of electricity, thus tending to suppress altogether the flash of Lightning; and if the flash of

Lightning does come, it is much more likely to strike the wood than to strike you; because the wood is a far more prominent body, and offers, on the whole, an easier path to earth. In like manner, if you place yourself near a tall solitary tree, some twenty or thirty yards outside its longest branches, you will be in a position of comparative safety. If the storm overtake you in the open plain, far away from trees and buildings, you will be safer lying flat on the ground than standing erect.

In an ordinary dwelling-house, the best situation is probably the middle story, and the best position in the room is in the middle of the floor; provided, of course, that there is no gasalier hanging from the ceiling above or below you. Strictly speaking, the *middle of the room* would be a still safer position than the middle of the floor; and nothing could be more perfect than the plan suggested by Franklin, to get into "a hammock, or swinging bed, suspended by silk cords, and equally distant from the walls on every side, as well as from the ceiling and floor, above and below." An interesting case has been recently recorded, by a resident of Venezuela, which illustrates in a remarkable way the excellence of this advice. "The lightning," he says, "struck a *rancho*—a small country house, built of wood and mud, and thatched with straw or large leaves—where one man slept in a hammock, another lay under the hammock on the ground, and three women were busy about the floor; there were also several hens and a pig. The man in the hammock did not receive any injury whatever, whilst the other four persons and the animals were killed." [1]

[1] Nature, vol. xxxi. p. 459.

But as I can hardly hope that many of you, when the Thunderstorm actually comes, will find yourselves provided with a hammock, I would recommend, as more generally useful, another plan of Franklin's, which is simply to sit on one chair, in the middle of the floor, and put your feet up on another. This arrangement will approach very nearly to absolute security, if you take the further precaution, also mentioned by Franklin, of putting a feather bed or a couple of hair mattresses under the chairs.[1]

Security afforded by Lightning Rods.—You might, perhaps, be inclined to infer hastily, from the examples I have set before you, in the course of this Lecture, of buildings which were struck and severely injured by Lightning, though provided with Lightning Conductors, that a Lightning Rod affords a very imperfect protection to life and property. But such an idea would be entirely at variance with the evidence at hand on the subject. In all the cases to which I have referred, and in many others which might easily have been cited, the damage was done simply because the Lightning Rods were deficient in one or more of the conditions, on which I have so much insisted. Where these conditions are fulfilled, the Lightning flash will either not come down at all upon the building, or if it do come, it will be carried harmless to the earth.

Perhaps there is no one fact that so forcibly brings home to the mind the complete protection afforded by Lightning Conductors, as the change which followed their introduction

[1] See further information on this interesting subject in the Report of the Lightning Rod Conference, pp. 233–5.

into the Royal Navy. I have already told you that, in former times, the damage done by Lightning to ships of the Royal Navy was a regular source of expenditure, amounting, every year, to several thousand pounds sterling. But after the general adoption of Lightning Conductors, about forty years ago, through the indefatigable exertions of Sir William Snow Harris, this source of expenditure absolutely disappeared, and injury to life and property has long been practically unknown in Her Majesty's Fleet.

I should say, however, that the trial of Lightning Conductors in the Navy, though it lasted long enough to prove their perfect efficiency, has almost come to an end in our own days. The great iron monsters, which, in recent times, have taken the place of the wooden ships of Old England, are quite independent of Lightning Rods, in the common sense of the word. Their ponderous masts are virtually Lightning Rods of colossal dimensions, and their unsightly hulls are, so to speak, earth-plates of enormous size, in perfect electrical contact with the ocean. To add to such structures Lightning Conductors of the common kind, would be nothing better than "wasteful and ridiculous excess."

As regards buildings on land, I may refer to the little province of Schleswig-Holstein, of which I have already spoken to you. From some cause or other this small peninsula is singularly exposed to Thunderstorms, and of late years it has been more abundantly provided with Lightning Conductors than, perhaps, any other district of equal extent in Europe. Now, as a simple illustration of the protection afforded by these Lightning Conductors, I may mention that, on the twenty-sixth of May, 1878, a violent Thunderstorm

burst over the little town of Utersen. Five several flashes of Lightning fell in different parts of the town, but not the slightest harm was done, each flash being safely carried to earth by a Lightning Conductor. Further, it appears from the records of the Fire Insurance Company that, out of 552 buildings injured by Lighting, during a period of eight years—from 1870 to 1878—only four had Lightning Conductors; and in these four cases it was found, on examination, that the Lightning Conductors were defective.[1]

It would be easy to multiply evidence on this subject. But as I have already trespassed, I fear, too far on your patience, I will content myself with saying, in conclusion, that according to all the highest authorities, both practical and theoretical, any structure provided with a Lightning Conductor, properly fitted up, in conformity with the principles I have set before you to-day, is perfectly secure against Lightning. The Lightning, indeed, may fall upon it, but it will pass harmless to the earth; and the experience of more than a hundred years has fully justified the simple and modest words of the great inventor of Lightning Conductors: "It has pleased God, in His goodness to mankind, at length to discover to them the means of securing their habitations and other buildings from mischief by Thunder and Lightning."

[1] See Die Theorie, die Anlage, und die Prüfung der Blitzableiter, von Doctor W. Holtz, Greifswald, 1878.

Note I.

On the Lightning Conductor at Berehaven.[1]

It is satisfactory to know that the Lightning Conductor referred to in my Lecture, as attached to the Lighthouse at Berehaven, has been put in good order under the best scientific guidance. The following interesting letter from Professor Tyndall, which appeared in The Times, August 31, 1887, gives the history of the matter very clearly, and fully bears out the views put forward in my Lecture :—

"Your recent remarks on Thunderstorms and their effects induce me to submit to you the following facts and considerations. Some years ago a rock lighthouse on the coast of Ireland was struck and damaged by Lightning. An engineer was sent down to report on the occurrence, and as I then held the honourable and responsible post of scientific adviser to the Trinity House and Board of Trade, the report was submitted to me. The Lightning Conductor had been carried down the lighthouse tower, its lower extremity being carefully embedded in a stone, perforated to receive it. If the object had been to invite the Lightning to strike the tower, a better arrangement could hardly have been adopted.

"I gave directions to have the Conductor immediately prolonged, and to have added to it a large terminal plate of copper, which was to be completely submerged in the sea. The obvious convenience of a chain as a prolongation of the Conductor caused the authorities in Ireland to propose it; but I was obliged to veto the adoption of the chain. The contact of link with link is never perfect. I had, moreover, beside me a portion of a chain cable through which a Lightning discharge had passed, the electricity in passing from link to link encountering a resistance sufficient to enable it to partially fuse the chain. The abolition of resistance is absolutely necessary, in connecting a Lightning Conductor with the earth, and this is done by closely embedding in the earth a plate of good conducting material and of large area. The largeness of area

[1] See page 124.

makes atonement for the imperfect conductivity of earth. The plate, in fact, constitutes a wide door, through which the electricity passes freely into the earth, its disruptive and damaging effects being thereby avoided.

"These truths are elementary, but they are often neglected. I watched with interest some time ago the operation of setting up a Lightning Conductor on the house of a neighbour of mine in the country. The wire rope, which formed part of the Conductor, was carried down the wall, and comfortably laid in the earth below, without any terminal plate whatever. I expostulated with the man who did the work, but he obviously thought he knew more about the matter than I did. I am credibly informed that this is a common way of dealing with Lightning Conductors by ignorant practitioners, and the Bishop of Winchester's palace at Farnham has been mentioned to me as an edifice 'protected' in this fashion. If my informant be correct, the 'protection' is a mockery, a delusion, and a snare."

Note II.

Books of Reference.

As some of my readers may wish to pursue the study of Lightning and Lightning Conductors beyond the limits to which a popular Lecture must, of necessity, be confined, I subjoin a list of the books which, I think, they would be likely to find most useful for the purpose. Among ordinary Text-books on Physics, Jamin, Cours de Physique, vol. i. pp. 470–494; Mascart, Traité d'Electricité Statique, vol. ii. pp. 555–579; de Larive, A Treatise on Electricity, in three volumes, London, 1853–8, vol. iii. pp. 90–201; Daguin, Traité de Physique, vol. iii. pp. 209–280; Riess, Die Lehre von der Reibungs-Elektricität, vol. ii. pp. 494–564; Müller-Pouillet, Lehrbuch der Physik, Braunschweig, 1881, vol. iii. pp. 210–225; Scott, Elementary Meteorology, chap. x. Of the numerous special treatises and detached papers on the subject, I would recommend, Instruction sur les Paratonnerres adoptée par l'Académie des Sciences, Part i. 1823, Part ii. 1854, Part iii. 1867, Paris, 1874; Arago

Sur le Tonnerre, Paris, 1837; also his Meteorological Essays, translated by Sabine, London, 1855; Sir William Snow Harris, On the Nature of Thunderstorms, London, 1843; also by the same writer, A Treatise on Frictional Electricity, London, 1867; and various papers on Lightning Conductors, from 1822 to 1859; Tomlinson, The Thunderstorm, London, 1877; Anderson, Lightning Conductors, London, 1880; Holtz, Ueber die Theorie, die Anlage, und die Prüfung der Blitzableiter, Greifswald, 1878; Weber, Berichte über Blitzschläge in der Provinz Schleswig-Holstein, Kiel, 1880–1; Tait, A Lecture on Thunderstorms, delivered in the City Hall, Glasgow, in 1880, Nature, vol. xxii.; Report of the Lightning Rod Conference, London, 1882. This last-mentioned volume comes to us with very high authority, representing, as it does, the joint labours of several eminent scientific men, selected from the following Societies: The Meteorological Society, the Royal Institute of British Architects, the Society of Telegraph Engineers and Electricians, the Physical Society.

Since the above was in print two Lectures, given before the Society of Arts, by Professor Oliver Lodge, F.R.S., have appeared in The Electrician, June and July, 1888, in which some new views are put forward respecting Lightning Conductors, that seem deserving of careful consideration.

THE

STORING OF ELECTRICAL ENERGY.

A LECTURE

DELIVERED IN THE THEATRE OF THE ROYAL DUBLIN SOCIETY,

MARCH, 1882.

A LECTURE

ON

THE STORING OF ELECTRICAL ENERGY.

IN the early part of last summer, an account was published in The Times newspaper of a "marvellous box of electricity," one cubic foot in size, which, it was said, had been carried from Paris to Glasgow, and there deposited in the laboratory of Sir William Thomson. A few weeks later, a letter appeared from Sir William Thomson himself, stating that he had carefully examined the box; that he had found it to contain a million foot-pounds of energy; and that when this store was exhausted, it could be easily renewed, so as to be again ready for use. Further, he told us, in effect, that a few of these boxes, laid by in a cellar, might be charged from time to time from a central factory, and might be used as occasion required, either to drive machinery, or to light up a drawingroom. With the aid of such boxes, a tramcar might dispense with horses, and a railway train with steam engines. Nay, he said, the vast energies of the Falls of Niagara might be stored up in these wonderful boxes, and used as the chief source of light and power for the whole continent of North America.

These statements are, perhaps, tinged with the glow of enthusiasm, naturally excited in a great mind, when it con-

templates the first dawn of a new discovery, and glances forward, by anticipation, to its future history. But the simple facts of the discovery, even when expressed in the sober words of science, are quite sufficient to account for the

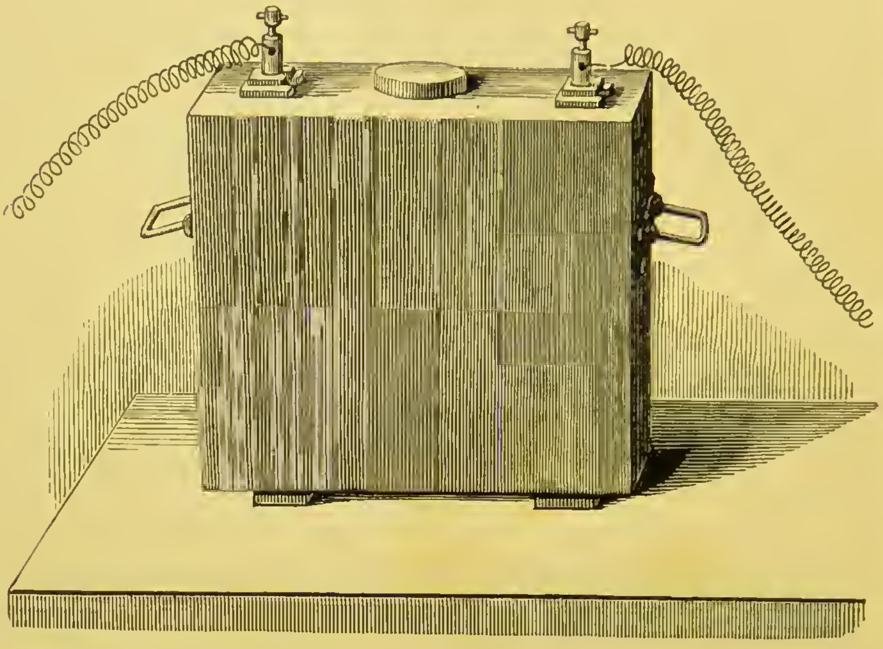

Fig. 21.

The "Marvellous Box of Electricity."

wide-spread interest it has awakened. This "box of electricity," as it has been called, is nothing more or less than a kind of store, in which electrical energy is laid by, so to say, and kept ready for use when wanted. Its practical value can be fully determined only by actual trial: but this much may be said, even now, that it gives fair promise of bringing more completely under our control one of the most potent and mysterious forces of nature.

My object to-day is to give you some account of this new discovery; to tell you what it is in itself, and how it stands

in relation to our previous knowledge; how it comes opportunely, as it were, to fill a vacant place, and puts it in our power to deal with the energy of the electric current as we have long been accustomed to deal with other forms of energy.

Examples of Energy Stored up.—At the outset, let me try to bring home clearly to your minds what is meant when we

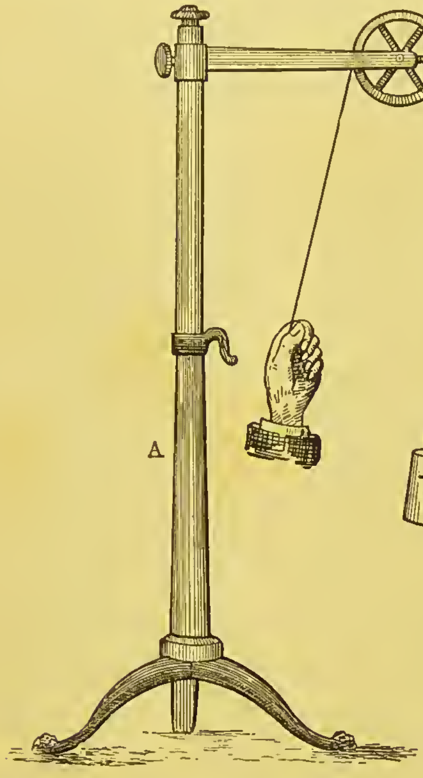

Fig. 22.

Energy Expended in doing Work.

A Stand supporting the Pulley P. | W Weight of 7lbs., lifted up one foot.

speak of storing energy. Energy is the capacity of doing work; and it is measured by the amount of work that is done when the energy is expended. Here is a weight of seven

pounds resting on the table. It is tied to one end of a string which passes over a pulley. When I pull down the other end of the string, I pull up the weight, say to a height of one foot. In doing so, I expend a certain amount of energy, and I do a certain amount of work. If I call the work done, when a pound weight is lifted one foot high, a foot-pound, then the work done, when a weight of seven pounds is lifted one foot high, will be seven foot-pounds; and this is the measure of the energy I have expended in pulling up the weight before you.

Now I want to show you that the energy so expended is stored up in the weight, so long as it remains in the position to which I have raised it. You know that if I leave the weight to itself, it will fall back to the table, and that in falling back it is able to do work: therefore, in virtue of its present position, it has the capacity of doing work; that is, it has energy. I may store up that energy indefinitely, by simply hooking on the string to this stand, so as to keep the weight suspended at a height of one foot from the table. But, on the other hand, I may draw upon my store of energy whenever I please, and use it to do work. Here is a little bucket of shot, which weighs somewhat less than seven pounds. I hook it on to the free end of the string, and then let go. The weight falls down one foot, and the bucket of shot goes up one foot.

If we consider the work done, by the falling weight, on the bucket of shot, we shall see that it is a little less than seven foot-pounds, since the bucket of shot weighs somewhat less than seven pounds. But the falling weight has done another kind of work: it has overcome the friction of the

pulley. And moreover, when it reached the table it had still a little energy left, which it expended in a feeble blow. Now, if we were to measure the energy of that blow, and add it to the energy spent in overcoming friction, and add both, taken together, to the work done on the bucket of shot, the

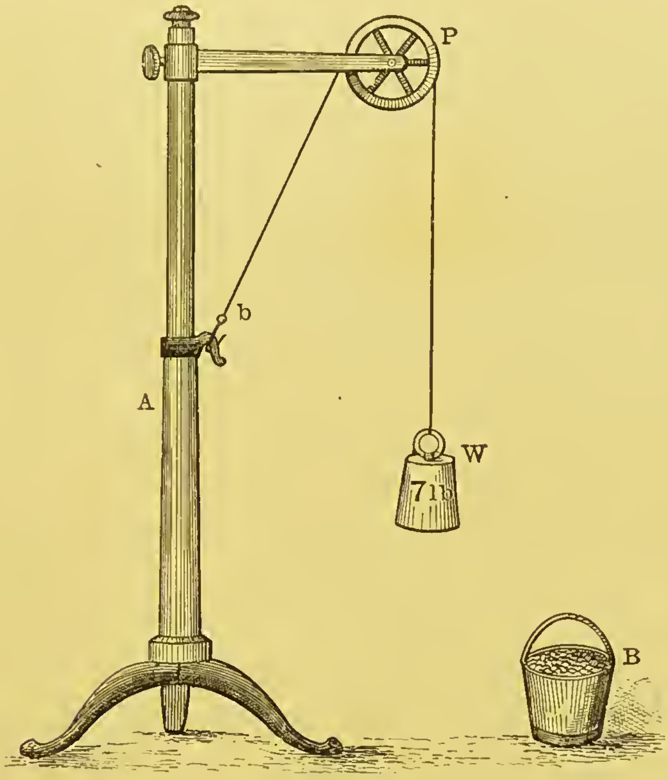

FIG. 23.

ENERGY STORED UP IN A SUSPENDED WEIGHT.

A Stand supporting the Pulley P.
B Bucket filled with Shot.
W Weight kept suspended by the Hook *b*.

whole would be equal to seven foot-pounds of work; and thus we should find that our weight, in falling back to the table, did work which is the exact equivalent of the energy I

had expended in pulling it up. In this sense, the energy expended by me may be said to have been stored in the uplifted weight.

You will find an interesting illustration of this principle in a common eight-day clock. The works of the clock are driven by the weights; and the weights, in doing their work, are always falling slowly towards the ground. When at length they can fall no further, they can do no more work, and the clock is said to have run down. If we want to set it going again we must wind it up; that is, we must lift up the weights into a position from which they can fall down again. In doing so, we expend muscular energy, and the energy so expended is practically stored up in the weights, to be given out slowly and continuously, in the form of work, as they fall back towards the ground, during a period of several days.

In like manner, when you wind up a watch, you lay in a store of energy, by coiling up an elastic spring; and the spring expends this energy in doing work, as it slowly uncoils itself, and imparts motion to the wheels of the watch. Again, when I pump air into this air-gun, I lay up a store of energy in the form of compressed air; and I can draw upon that store at pleasure, and use it for the purpose of discharging bullets from the barrel of the gun.

It would be easy to multiply examples; but my object is not so much to treat this branch of the subject exhaustively, as to suggest familiar illustrations of a general principle. Everyone can supply new examples from his own experience. Thus a steam-hammer lifted up has a store of energy, which it expends, in doing work, when it falls, by its own weight,

on the anvil. A cross-bow stretched has a store of energy, which is ready at any moment to send an arrow flying through the air. A cannon-ball discharged from the mouth of a cannon has energy stored up, which does work in tearing asunder the massive armour of an iron-clad vessel. The fly-wheel of a gas-engine receives, at each explosion, a store of energy, which it expends in keeping up the movement of the machinery until the next explosion comes.

Energy Stored up in Clouds and Rivers.—Sometimes energy is stored up for us by a natural process, and we have nothing to do but to use it. You have seen that there is a store of energy in an uplifted weight, and that we may use this energy for the purpose of doing work, as the weight falls back to its former level. But it may not have occurred to you that Nature is always busy, laying up for us a store of energy of this kind, which is practically inexhaustible. She is always lifting up the water of the ocean in the form of vapour, and setting it down again on the summits of our hills and mountains, in the form of rain and hail and snow. There it gathers into rivulets, and the rivulets coming together form streams, and the streams sweep down into the valleys, and flow back as stately rivers to the parent ocean. And all along its course, this falling water, as you know, has within it a store of energy, which it is ever ready to give out in doing work for us—in grinding corn, or in sawing timber, or in driving machinery.

Energy Stored up in Coal-Mines.—So much for the storing of what may be called mechanical energy. I should now wish to give you one or two illustrations of the way in which the energy of heat may be stored up. I need not

tell you how largely the energy of heat is employed, in the form of steam, to do the work of the world. Now we get this heat, as a general rule, by the combustion of coal; and therefore a coal-mine is a vast store of energy, always available to drive our machinery and to do our work.

Here, again, we are indebted to the beneficent foresight of Nature. Long ages ago this store of energy was laid up for us, in the primeval forests of that ancient time which is known to geologists as the Carboniferous Period. The rich and luxuriant vegetation of those primeval forests was mainly composed of certain chemical compounds of carbon and hydrogen, which were drawn off from the air and the earth by the action of natural forces, and built up into the structure of plants and trees. Ages rolled by; generation after generation of that ancient life flourished and decayed; the dry land was submerged beneath the ocean; new strata were spread out over the sunken forests; and by a slow and gradual process the vegetation of that long-past time was compacted into beds of coal. But after all these changes, the hydro-carbon compounds, built up in the primeval forests, still survive in the coal, and constitute, in fact, the source of all the heat that is given out when coal is burned.

It is worth while to pause for a moment, and consider the actual process of combustion by which this heat is developed. Hydrogen has a great natural attraction for oxygen, and so has carbon. In consequence of this attraction they are ready, under certain conditions, to part company with one another, and to combine, each of them, with oxygen, thus forming new chemical compounds. When we light a fire we produce the required conditions, and the

process then goes on until all the coal is burned away. The hydrogen combines with oxygen, and forms water; the carbon combines with oxygen, and forms carbonic acid. Thus the coal is converted, by combustion, into water and carbonic acid; a small quantity only, which is incombustible, remaining behind in the form of ashes.

But what is the physical cause of the heat produced in this process? You remember that a weight in falling to the ground, under the attraction of gravitation, can do work for us. If, however, it be allowed to fall without doing work, it reaches the ground with its full store of energy unimpaired, and expends it all in a single blow. Now it has been fully demonstrated by experiment that, by this blow, the energy of the falling weight is converted into the energy of heat. And it would seem that the heat produced in combustion is generated by a somewhat similar action. The atoms of hydrogen and carbon clash with the atoms of oxygen, and heat is evolved in the collision. In the case of a falling weight, a mass of sensible magnitude, moving through a sensible distance, strikes against another mass; in the case of combustion, millions upon millions of minute atoms, moving through indefinitely small distances, strike against each other. But in both cases alike, the energy of moving bodies is converted into the energy of heat.

Energy Stored up in Separated Gases.—And now we can see more clearly what it is exactly that makes coal a store of heat energy: it is the fact, that in coal we have carbon and hydrogen, on the one hand, existing apart from oxygen, on the other, with a chemical force acting between them, and tending to pull them together. Proceeding from this idea,

it is easy to conceive how we can lay up for ourselves a store of this kind of energy. Water, as you know, is a chemical compound of oxygen and hydrogen. Now, on the table before you is a voltaic battery, and near the battery is a glass vessel containing acidulated water. When I send a current of electricity from the battery through the water, the molecules of water are pulled asunder by the action of the current, and resolved into their constituent elements. You can plainly see the gases as they rise in multitudes of bubbles, in these two glass tubes, which are now brilliantly illuminated by a beam of light from the lantern. The oxygen is set free in the tube to your left, where the current enters the liquid; the hydrogen in the tube to your right, where the current leaves the liquid.

What I want you to observe, in this beautiful and interesting experiment, is, that we are here expending a certain kind of energy—the energy of an electric current—in doing a certain kind of work, that is, in pulling asunder the atoms of oxygen and hydrogen against the force of attraction, which tends to keep them locked together in close chemical union. The two gases, thus forcibly separated, have a strong tendency to combine again, and when they do combine, they will generate new energy in the form of heat.

To impress this important fact distinctly on your minds, I will now get these gases to combine chemically before you. You see on the table, side by side, two small bags, one filled with oxygen, the other with hydrogen. And here is an apparatus known as the oxy-hydrogen lamp. It has one tube connected with the bag of oxygen, another with the bag

of hydrogen. The two tubes communicate, by means of these stop-cocks, with the same common jet, where I mean to bring the gases into intimate contact, under circumstances favourable to their chemical combination.

First turning one of the stop-cocks, I allow the hydrogen to flow out, and when a lighted taper is applied to the jet, the hydrogen burns with a pale blue flame. This flame, though but faintly luminous, is intensely hot, as I can easily show you. Here is a spiral of platinum wire, and you see, when it is held in the flame, it at once begins to glow with a steady white light. The heat that is here produced is due to the combination of the hydrogen, coming from our bag, with the oxygen present in the air around us. But it becomes far more intense when I turn the second cock, and thus pour a stream of pure oxygen into the jet of glowing hydrogen. To give you some practical evidence of the heat that is now yielded up by our store of energy, I take this piece of steel wire and hold it in the flame. See how it burns away like tinder, and scatters about a shower of brilliant sparks. I put aside the wire, and in its stead I hold a rod of chalk in the burning jet. The chalk does not burn, but it glows with intense heat, and sends forth a light of almost overpowering splendour.

These are pretty experiments, and in many ways instructive. But for our present purpose I would ask you to fix your attention on one point only: that all the heat and light, produced in the flame of our lamp, is due to the clashing together of the hydrogen and oxygen atoms, under the force of chemical attraction. Now they never could have clashed together, unless they had first been pulled asunder. And

therefore, in pulling them asunder, we gave them the capacity of producing that heat and light.

This is the sense in which the energy of heat may be said to be stored up in these two bags of oxygen and hydrogen. In the same sense it is also true that the energy of heat is stored up in a piece of coal. And in a similar sense, as we have seen, there is a store of mechanical energy in an uplifted weight, in a running stream, in a stretched cross-bow, in a cannon ball shooting through the air.

Storing of Electrical Energy not a New Idea.—Having now before us, as I trust, a clear conception of what is meant by the storing of mechanical energy, and the storing of heat energy, we may pass on to the subject of more immediate interest, the storing of electrical energy. It will, perhaps, be a surprise to some of you, to hear that the storing of electrical energy is not a new idea, but one that has long been familiar to the minds of scientific men. When a common electric machine is put in action, electrical energy is stored for a short time in the prime conductor, and is given out whenever a spark passes. It is stored, too, and more effectively, in a Leyden jar, when the Leyden jar is charged from the machine. And Nature, I need hardly tell you, has a way of her own for storing electrical energy in a thunder cloud.

Again, it may be said, with perfect truth, that every voltaic battery is a store of electrical energy. In a voltaic battery, some metal is employed, generally zinc, which, when the battery is working, is acted on chemically by an acid. The effect of this chemical action is that the atoms of the metal combine with the oxygen of the acid;

and by the act of combination an electric current is generated. Now observe how closely this process resembles the process by which heat is developed from coal. In the case of coal, we have carbon and hydrogen existing apart from oxygen, with a chemical force tending to make them combine, under suitable conditions. We set up these conditions when we light a fire: the chemical force then comes into action; the carbon and hydrogen rush to meet the oxygen; and in the clash of atoms heat is developed. Similarly, in the voltaic battery, we have zinc existing apart from oxygen, with a chemical force tending to pull them together. We bring this force into action when we arrange the cells of our battery, and make the necessary connections; the atoms of zinc and oxygen then clash together, and, by the energy of their collision, an electric current is generated.

Thus it is clear that, exactly in the same sense in which heat energy is said to be stored in a lump of coal, it may also be said that electrical energy is stored in the zinc plates of a battery. It is worth observing, too, that both cases furnish a striking illustration of a universal law of Nature. We cannot use our store of energy, and keep our store, at the same time. We cannot get heat from coal, except by a process in which the coal is burned, and ceases to exist as coal. And so, too, we cannot get an electric current from our zinc plates, except by a process in which the zinc is gradually consumed, and ceases to exist as zinc.

But you will ask me, If every voltaic battery is practically a store of electrical energy, how is it that the discovery of a means of storing electrical energy has caused so great a sensation within the last twelve months? Is it to be said

that we are able to do no more, with the aid of this new discovery, than we were able to do without it? I have led up to this question, because I want you to understand what it is precisely that this new discovery promises to do for us.

First, then, let me tell you that, although an ordinary voltaic battery is a store of electrical energy, it is an expensive store. To get an electric current from the battery we must, as I have just told you, consume the zinc plates, and zinc is an expensive metal. Speaking roughly, I may say that it costs about twenty times as much as coal, weight for weight. Again, the arrangements that must be made, in order to get an electric current from the zinc, involve the use of other costly materials, such as nitric acid and sulphuric acid ; they also involve the constant attendance of skilled hands. Hence it was found out, long ago, that the voltaic battery, however useful it may be in a scientific laboratory, or on certain special occasions, when cost is a matter of little moment, cannot be employed with advantage to supply electricity, on a large scale, for public use.

The Storage Battery.—Now the new discovery—the storage battery, as it has been very naturally called—differs from the ordinary voltaic battery in this, that it does not, of itself, give us an electric current, but it gives us a means of storing the energy of an electric current obtained from some other source. Thus you see, at once, that it would be of no practical use unless we had at hand some cheap and convenient way of producing electricity. But this want has been most opportunely supplied within the last few years. The dynamo-electric machines, which have now been brought to so high a degree of perfection, place at our

disposal a supply of electricity which is at once very cheap, and practically unlimited in amount. In fact, it is the rapid and extraordinary development of these machines that has brought into such prominence, at the present moment, the question of using electricity as one of the ordinary agents of light and power.

This question, I need hardly say, is surrounded by many difficulties, some of which have been partially overcome, and some have yet to be encountered. But it is agreed, on all hands, that few difficulties would remain unconquered, if, having got a cheap supply of electrical energy, we could now cheaply store it up, in a convenient form, and keep it ready for use, as occasion might require. This is a problem eminently attractive to the man of science, and not less attractive to the practical man of business; and it is because the new storage battery seems to give fair promise of solving it, that it has created so great a sensation, and awakened so wide an interest.

The object of this battery is simply to make an electric current store up its own energy, in a form suitable for future use; and I will now try to give you some idea of the way in which this object is attained. We have already seen that when a current of electricity, coming from a voltaic battery, or from any other source, passes between two metal plates immersed in acidulated water, the water is decomposed by the action of the current, oxygen being set free at the surface of one plate, and hydrogen at the surface of the other. As a result of this decomposition, a new force is set up within the liquid, which opposes the passage of the current, and tends to

produce a current of its own, flowing in the opposite direction. If now the battery current is cut off, and the two metal plates are connected by a wire, outside the liquid, this new current will begin to flow, and to produce electrical phenomena in the circuit thus formed. The electric current obtained in this way is called a secondary current, to distinguish it from the current coming from without, which is called the primary current.

Experiment to show Secondary Current.—I should like to demonstrate to you by experiment the existence of this

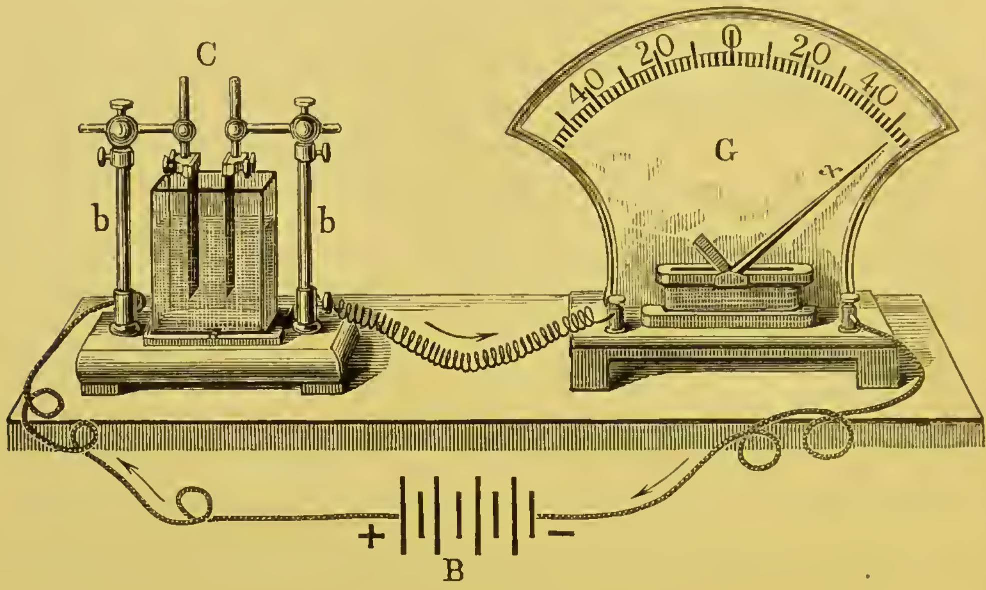

Fig. 24.

Decomposition Cell: Primary Current Flowing.

C Decomposition Cell.
b b Brass Pillars.
G Galvanometer.
B Battery.
x Index of Galvanometer, deflected to the right.

secondary current. Here is a glass cell containing acidulated water. Plunged in the water you can see two metal

plates: one is connected, by this brass pillar and a flexible wire, with the positive pole of a battery; the other is connected, by a second brass pillar and another wire, with one of the binding screws of a lecture table galvanometer; and the second binding screw of the galvanometer is con-

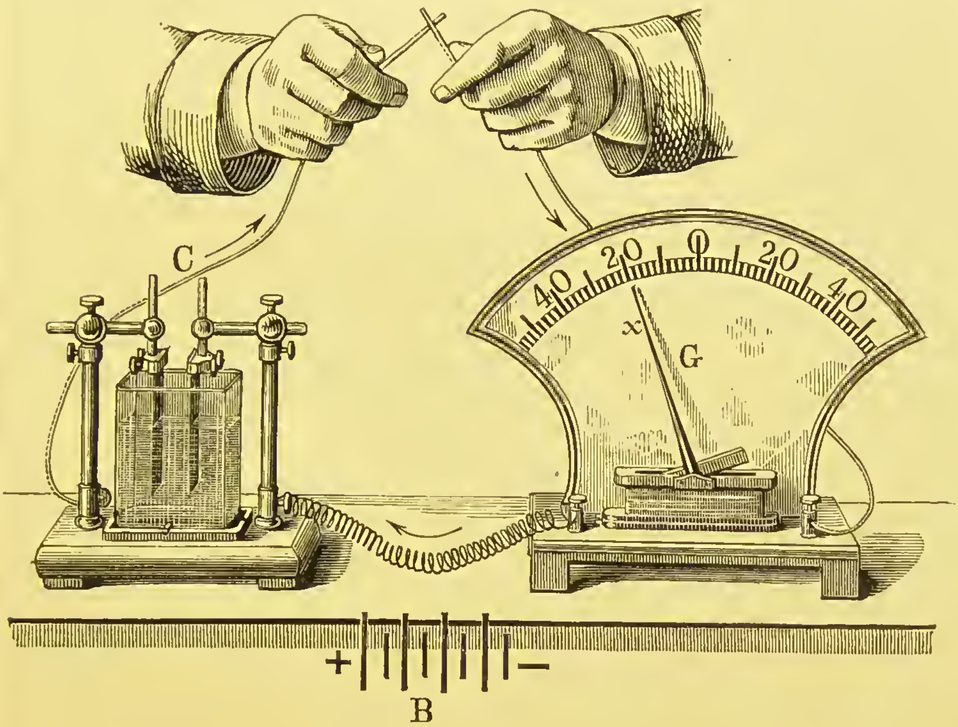

FIG. 25.

SAME CELL: SECONDARY CURRENT FLOWING.

C Decomposition Cell.
G Galvanometer.

x Index of Galvanometer, deflected to the left.

nected with the negative pole of the battery. By this arrangement the current from the battery is made to pass first through the acidulated water in the glass cell, and then through the galvanometer. When I put the battery

in action, observe how the index of the galvanometer is at once deflected, showing that the current is passing. At the same moment bubbles of gas begin to appear in the glass cell, showing that the process of decomposition is going on. After the lapse of a few seconds, I break the circuit, and cut off the battery current. The bubbles of gas are no longer developed, and the index of the galvanometer returns to zero.

Let us now try if the glass cell, with its metal plates, can give us a current of its own. For this purpose I will take the wire coming from the first metal plate, and bring it into contact with the wire attached to the second binding screw of the galvanometer. The circuit will then be the same as it was in the first part of our experiment, with this difference only, that the battery is left out. When I make contact, mark how the index of the galvanometer is deflected, proving that a current has begun to pass; and observe, too, that it is deflected not to your right, as it was before, but to your left, showing that the direction of the current, from the cell, is opposite to that of the current which came from the battery.

Now I want you to see clearly, before we proceed further, that this is a case of energy stored up. The energy of the primary current was first expended in doing a certain work, that is, in decomposing the molecules of water. As a direct consequence of this work, we had oxygen and hydrogen existing apart, with a chemical force acting between them, and tending to pull them together. This was our store of energy; and we drew upon the store when we cut off the battery, and completed the circuit

between the two plates of the decomposition cell. The chemical force was thus brought into action, the oxygen and hydrogen began to combine again within the cell, and in the act of combining they yielded an electric current.

I have dwelt at some length on this simple and familiar experiment, because it exhibits in a very clear light the fundamental principle of storage batteries. Some chemical change is produced within the storage cell, by means of a current of electricity which is made to flow through it; and in virtue of this change, the cell has a store of energy which it is ready to yield up, under suitable circumstances, in the form of an electric current. It remains for me now to describe briefly the principal attempts that have been made to apply this principle to practical purposes.

Ritter's Secondary Pile.—The earliest form of storage battery was made just eighty years ago, in Germany, by Ritter, of Jena. He took two small circular discs of copper, and between them he placed a similar disc of cloth, steeped in acidulated water. This combination constituted one element of his battery. He made a second element of the same kind, and laid it down on the first; a third, and placed it on the second; and so on, until he had built up a pile, or column, consisting of fifty or sixty elements. He now sent an electric current through the pile, from top to bottom; the water in the discs of cloth was decomposed, a counter electromotive force was set up in each element, and when the battery was cut off, the pile yielded, for a short time, an electric current of considerable power. This battery is known as Ritter's Secondary Pile; but as the current lasts only for a few minutes, it is of little practical use.

Grove's Gas Battery.—Forty years passed away, and Ritter's secondary pile was almost forgotten, when a new form of secondary battery was devised by Sir William Grove, who was, at the time, Professor of Experimental Philosophy in the London Institution, and is now one of the Judges in the High Court of Justice in England. His plan was to combine together a series of decomposition cells, such as the one

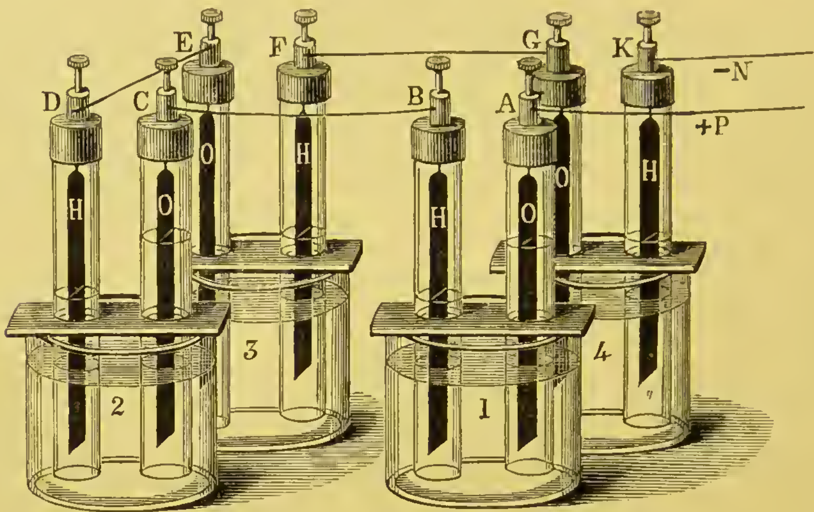

Fig. 26.

Grove's Gas Battery.

1, 2, 3, 4, Cells of the Battery.
A B, C D, E F, G K, Glass Tubes closed at the Top, and filled with acidulated Water.
P Wire by which the Charging Current enters the Battery.
N Wire by which the Charging Current leaves the Battery.
O Strips of Platinum Foil at which Oxygen is set free.
H Strips of Platinum Foil at which Hydrogen is set free.

with which we have just been making our experiments. Into each cell he introduced two glass tubes, closed at the top, and filled with acidulated water. Every tube contained a long strip of platinum foil; and when the primary current was

sent through the series of cells, it entered each cell by one platinum plate, and passed out by the other.

An arrangement of this kind, consisting of four cells, is on the table here before you; and you will observe that now, when I send the primary current through, crowds of little bubbles appear in every tube, while the galvanometer, which is also in circuit, indicates by its deflection that a strong current is passing. After a little time, those who are near can see that, in each cell, oxygen is gradually accumulating in one tube, and hydrogen in the other. And now I cut off the battery current, and complete the circuit of our four cells. The secondary current at once makes itself manifest, and the deflection of the galvanometer indicates that the direction of the current is contrary to that in which the primary current had previously passed.

Planté's Experiments.—This combination of secondary cells is called Grove's Gas Battery. It has always been an object of great interest to scientific men; but for reasons on which I need not dwell, the current which it produces is extremely feeble, and quite unsuited for practical work. Eighteen years more passed by, and the secondary battery still remained in the obscurity of the scientific laboratory, when, in the year 1860, Monsieur Gaston Planté exhibited his now famous cell before the Academy of Sciences in Paris. I think it should always be distinctly recognized that Gaston Planté is the man to whose patient and laborious researches we are mainly indebted for the position which the secondary battery occupies, at the present moment, in the eyes of the world.

These researches were begun in the year 1859, and have

been continued, I may say, down to the present day. His first object was to discover what metal was the best fitted for storing up electrical energy in a decomposition cell. After a long series of experiments, in which he tried gold, silver, platinum, copper, and other metals, he finally satisfied himself that lead was the best suited for the object he had in view. In the case of most other metals, the oxygen and hydrogen, produced by the decomposition of water, exist only as little bubbles of gas clinging to the surface of the plates at which they are evolved. But in the case of lead, these gases effect a chemical change, which gives to the plates a new character, of a more or less permanent kind; and this new character constitutes, in effect, the store from which the secondary current is derived.

Further, Monsieur Planté discovered that it is possible to increase very much the natural capacity of lead plates for storing electrical energy, by putting them through a process which he called the *formation* of the plates. This process, which extends over a period of three or four months, is much too tedious and complicated to be described in detail on an occasion like the present. But I may say, generally, that it consists in sending a current of electricity through the cell, first in one direction and then in the other, several times in succession, with intervals of rest between; and that the final result is to produce on one plate a substantial layer of lead peroxide, and to reduce the surface of the other plate to the condition of spongy or finely divided metallic lead.

Here are two lead plates, which have been prepared in the manner described; and I will now show you that they contain a store of electrical energy, on which we may draw

at pleasure. I plunge them, at a short distance apart, in a glass containing acidulated water; and then I connect them externally by a wire, including, as usual, the galvanometer in the circuit. The index of the galvanometer is immediately deflected to the extreme end of the scale, showing that a strong and steady current is going out from the cell. So long as the two plates retain their distinctive characteristics, so long will the current continue to flow. But, remember, we cannot use our store and keep our store at the same time. As the current continues to flow, oxygen is taken away from the layer of lead peroxide, and deposited on the layer of pure spongy lead; the peculiar character of each plate is thus gradually effaced; the store of energy becomes, in course of time, exhausted; and the current ceases to pass.

The capacity of such a cell as this, for storing electrical energy, increases as the surface of the metal plates is increased. It was, therefore, an object with Monsieur Planté, in the construction of his cell, to have the largest possible surface of lead in a convenient and portable form. To attain this end, he took two plates of lead, about ten inches in breadth, and from twenty to thirty inches in length. These he laid one over the other, separating them by narrow strips of india-rubber; then he rolled them up tightly together in the form of a scroll, and plunged the whole mass endwise into a cylindrical glass jar, containing dilute sulphuric acid. Next followed the process of *formation*, as already described, and the cell was then ready for use. I have here a Planté cell, which, as you see, is about one foot high and four inches in diameter. It was charged a few days ago, and when I now complete

the circuit, the current is powerful enough to raise this spiral of platinum wire to incandescence, and produce a brilliant white light.

Faure's Improvement.—The Planté secondary cell has long been used, with advantage, to store electrical energy for small surgical operations; it has been used also, to some extent, for the production of the electric light. But the *formation* of the plates is a process so tedious and costly

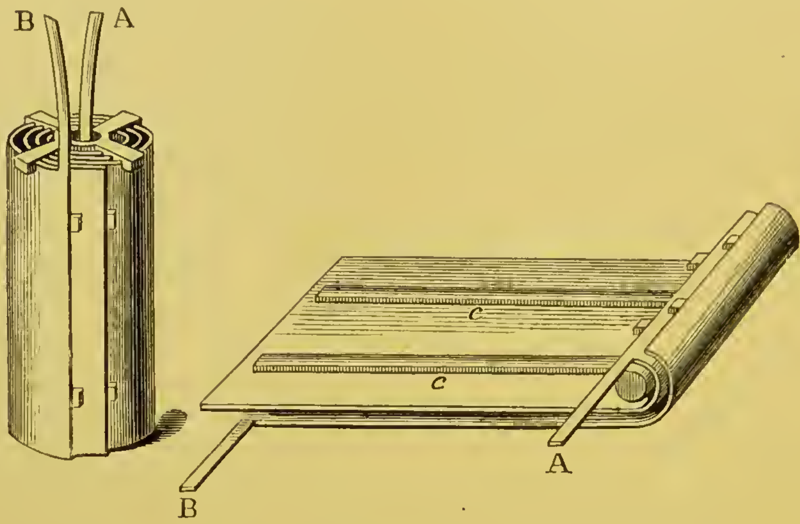

Fig. 27.

THE LEAD PLATES OF THE PLANTÉ CELL.

On the right, the Plates are seen opened out; on the left, they are seen rolled up.

A B Strips of Lead, one projecting from each Plate. | c c Strips of India-rubber to insulate the Plates.

that this form of cell, on a large scale, is not likely, I think, to come into general use. Hence a lively interest was awakened, last year, when it was announced that Monsieur

Faure, of Paris, had invented a new secondary battery, in which there was no need of such a process.

The plan adopted by Monsieur Faure may be explained in a few words. He first covers over the surface of the two

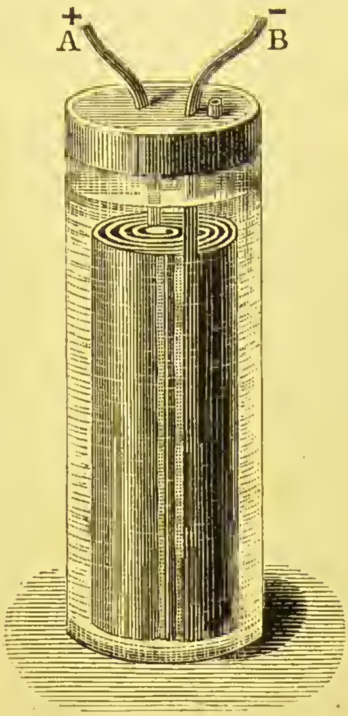

Fig. 28.

The Planté Cell Complete.

A Strip of Lead by which the Charging Current enters the Cell. | B Strip of Lead by which the Charging Current leaves the Cell.

lead plates with a thick layer of red oxide of lead; then he immerses them in a cell containing dilute sulphuric acid, and sends an electric current through the cell from plate to plate. The effect of the current is, practically, to deposit oxygen on the plate at which the current passes in, and to abstract it from the plate at which the current passes

out; thus raising the layer of red oxide, on the one plate, to the condition of lead peroxide, and reducing it, on the other, to the state of pure metallic lead. This change is accomplished in one or two days; and when it is complete, the cell has got its charge. It will keep this charge stored up, with very little loss, for a period of several days, or it

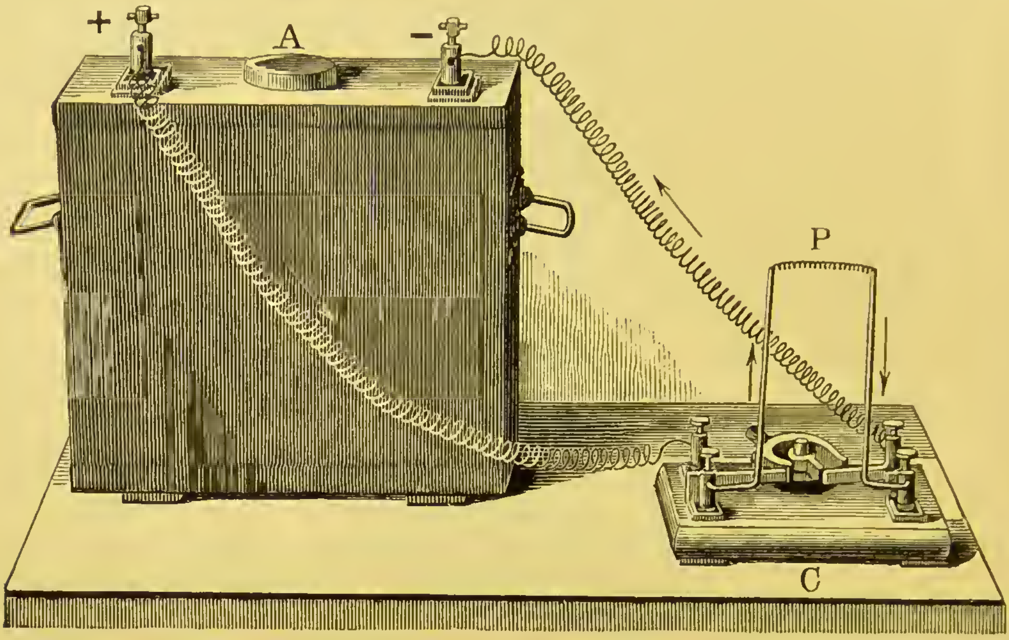

Fig. 29.

The Faure Cell in its Earliest Form.

A The Cell: A Wooden Box, with a Hole in the Top, closed with a Bung, for introducing the Acid.

C The Commutator.
P Platinum Spiral.

will give it out, at our pleasure, whenever it is wanted for use.

In practice Faure uses for his cell a rectangular box, which holds ten or twelve plates. Each plate is covered over tightly with felt to prevent the paste of red oxide

from falling off, and the plates are so connected together that they act as two single plates, of very large surface. The amount of electrical energy that can be stored in one of these cells may be expressed in terms of mechanical energy; and it has been determined, by accurate measurement, that a cell, weighing somewhat less than a hundred pounds, can store a million foot-pounds of energy, which is equal to one horse-power working for about thirty minutes. Such a cell as this, fully charged, is here on the table before you, and fairly represents the "marvellous box of electricity" which appeared in England, for the first time, last summer, and of which so much has been written and spoken during the past twelve months The wires coming from the two poles of the cell are connected, as you see, with the binding screws of this commutator; and when I turn the handle of the commutator, a current of electricity flows through a spiral of thick platinum wire, producing intense heat, which makes the wire glow.

What a Storage Battery can do.—You will have no difficulty now, I think, in understanding what a storage battery is, and what it is able to do. It is simply a number of these cells—twenty, thirty, or a hundred—ranged side by side, combining their forces together, and ready, at the turn of a handle, to pour forth a powerful stream of electricity, which we may use at pleasure, either to illuminate our houses or to drive our machinery. A small battery of this kind is set up here on the table beside me. At present the current is not flowing, and the energy of the battery remains stored up. But I now complete the external circuit by turning the handle of this

little commutator. In a moment half a dozen incandescent lamps scattered over the table are all aglow, shining with a brilliant white light.

At a little distance, on another table, are four more lamps which are still dark. I turn another handle, and they too begin to glow, while the first continue to shine as brightly as before. On the floor, at my left, is a circular saw, provided with an electro-motor to drive it. I turn a third handle, which brings the electro-motor into the circuit of our battery; the saw is driven rapidly round, and cuts right through a stout piece of timber which my assistant presses against it. By reversing the motion I can, of course, stop the machinery, or put out the lamps, just as I please; or I can shut off the current altogether, and the energy that remains will continue stored up in the battery, until it is again wanted for use.

But some one, perhaps, may be disposed to ask, What, after all, can be the use of a storage battery, if, as I have told you, we can get no electrical energy out of it except what we first put in? Is it not a new element of expense, interposed between the manufacture of an electric current and the consumption of it? I answer, it is useful because it is convenient. It promises to do for electricity what a gasholder does for gas: to store it up according as it is made, and to give it out according as it is wanted. Further, I say it is useful, because it puts it in our power to turn to useful account a vast supply of energy which is now simply going to waste. What the mill-pond does, on a small scale, for the miller, the storage battery promises to do for the whole population, on a scale of great magni-

tude: to catch the energy of the flowing stream, which is now running idly by, almost at our very doors, and to lay it up, in a convenient form, until we are ready to use it.

Practical Illustrations.—If I have not already trespassed too far on your patience, I should like to touch briefly on one or two illustrations of this interesting and practical question. Suppose you want to light your house with those beautiful incandescent lamps of which I have shown you some specimens here to-day, you have only to get a storage battery, proportioned in size to the illumination you require, and stow it away in a convenient corner of your basement floor. A wire is laid on to your house from a central station, your battery is charged every morning with a store of electrical energy, and you can draw on that store, to illuminate your house, just when you please, and how you please.

I may mention, in passing, that Mr. Edison has just invented a very simple apparatus to measure the amount of current that comes into your house: thus you will only have to pay for what you get. And Sir William Thomson has invented an apparatus which, of itself, will cut off the current as soon as your battery is fully charged: thus you will only get what you want, and none will go to waste. It may be observed, too, that if you desire a more than usually brilliant illumination, for some festive occasion, you have but to order a few extra cells and hire a few extra lamps.

Again, let me take the case of a small country town, with a waterfall near at hand, or a strong flowing stream. The energy of the falling water can be converted into an electric current, at hardly any cost, by means of dynamo-

electric machines. Then, if a large storage battery is provided for the illumination of the streets, and if each house has its own small battery for private use, the energy of the stream during the whole period of twenty-four hours can be stored up to light the town during the hours of darkness. A greater store of electrical energy will be wanted, of course, in winter than in summer, as the period of darkness is longer; but Nature happily provides for this increased demand by giving us, in winter, a stronger flow of falling water.

The Storage Battery as a Motive Power.—As a motive power, these storage batteries seem eminently fitted for driving tram-cars. An ordinary tram-car, with its full complement of passengers, weighs about four tons. To drive this weight, at the rate of six miles an hour, we should require an electro-motor working at about three or four horse-power on the level road, but capable of working up to eight or ten horse-power, in going over bridges and up steep inclines. Now, from the experience we already possess, I think I am safe in saying that the electrical energy required to work such a motor continuously, for two hours, can be stored up in boxes that would fit conveniently under the seats of the car. If this be so, then it would only be necessary to provide a large supply of these storage batteries at one end of the line; to set up a couple of steam engines which could be kept constantly at work, charging the batteries; and we might get rid, at once, of a whole troop of horses, with all their attendant expenses.

In the application of storage batteries to the driving of tram-cars, there is one point of especial interest on which

I would dwell for a moment. Every one must have observed what a great waste of energy takes place every time a tram-car is stopped on its journey. Moving at the rate of six miles an hour, it possesses, within itself, a very considerable store of energy, and before it can be pulled up all that energy must be destroyed. If it is destroyed by means of a break, it is simply wasted; if it is destroyed by the aid of the horses, as often happens, then not only is it wasted, but fresh energy is expended in wasting it; and when the tram-car is again started, the horses are called on for a new effort to develop once more the energy which has just been destroyed. Hence it has long been a project with mechanical engineers to devise some means of storing up the energy with which the tram-car is moving before it is stopped, and to use that store for starting it again. Up to the present time this project has been little more than a dream, but it would seem that these storage batteries now enable us to make it a reality.

When the battery is driving the tram-car, a current of electricity flows from the battery into the electro-motor, causing the bobbin of the electro-motor to rotate on its axis, and thus driving round the wheels of the tram-car, which are connected with the bobbin. But it is quite possible, by the mere turn of a handle, so to alter the relation between the electro-motive force of the battery and that of the motor, that this process shall be exactly reversed. The revolving wheels of the tram-car will then drive the bobbin round, thus generating an electric current, which will flow back into the cells, and charge the battery. The moment this change is made, the moving tram-car not only ceases to receive any

further impulse from the battery, but it is called upon to do work, in generating an electric current. In doing this work it rapidly expends its store of energy, and soon comes to a standstill. But the energy thus expended is not wasted; it is added to the store of energy already existing in the battery; and when the handle is turned back to its former position, it will help to start the tram-car again.

From tram-cars it is not a very violent transition to private carriages. No doubt, so long as our streets remain in their present condition, we must be content to jog along in the jolting and jarring fashion to which we are accustomed. But if I might fancy a time when our rugged pavement had given way to a smooth and pleasant flooring of asphalte, I see no reason why a box of these cells might not take the place of horses in carriages and other vehicles. On such a roadway one horse power would be amply sufficient to drive a fair-sized carriage, as fast as it would be safe to go through the streets of a crowded city; and a moderate-sized battery, which might be stowed away in a convenient recess of the carriage, could store up energy enough to yield the work of one horse for a drive of two or three hours.

The Storage Battery on its Trial.—And now, in coming to an end, I should wish to remind you of what I said in setting out, that the practical value of this storage battery can be fully determined only by actual trial. At the present moment, it seems to me somewhat in the condition of a hot-house plant; which blooms and flourishes so long as it is confined to the artificial atmosphere in which it has been nurtured, but which, when transferred to the open air of our gardens, is found, very often, unable to bear the rough winds

and the changeful climate of a ruder life. This secondary battery has hitherto been carefully and tenderly cherished, under the artificial conditions of the scientific laboratory; and under these conditions it has shown quite a wonderful and vigorous development. The time is now come when it will be called upon to encounter the rough usage and, so to say, the wear and tear of a working life. If, like a hardy plant, it is able to accommodate itself to these new conditions, and continues still to flourish and to develop fresh growth, then there is not one of the speculations I have set forth which may not be realized, even in our own day. But if it should break down under the trial that awaits it, and if our speculations should come to nought, nevertheless the great principles on which I have been insisting—which rest on the solid foundations of science, and which we have found so beautifully illustrated by the secondary battery—these principles will still survive, and the time we have spent in discussing them will not, I trust, have been spent in vain.

On the Recent Progress and Development of the Storage Battery.

Soon after the date of the above Lecture, the storage battery began gradually to come into use, for practical purposes. In many respects it amply fulfilled the hopes awakened by its first discovery. But, as in the case of most other inventions, when it was put to actual trial, some unexpected difficulties presented themselves.

Modifications of the Faure Cell.—In the first place, it was found that, after the Faure Cell had been a little time in use, the current leaked across from one plate to the other, through the flannel, or felt, by which they were separated; and of course the current, in so far as it thus leaked from plate to plate, was practically wasted, and ceased to be available for useful work. To meet this inconvenience, the felt was got rid of, and the plates were kept in position by short studs of ebonite, or india-rubber, fixed between them. An incidental advantage of this change was that the internal resistance of the cell was reduced: a matter of great importance in connexion with Electric Lightning.

It became, however, necessary to devise some means by which the paste of lead oxide might be made to adhere firmly to the plates, when deprived of the support which it had previously received from the felt. This has been effected by a new method of preparing the lead plates. Before the paste is put on, every plate is honeycombed on each surface with an immense number of quadrangular indentations, or cells, sinking some distance into the thickness of the plate. The paste of lead oxide is then pressed into these cells, and when it dries it holds a firm grip of the plate, and presents a uniform surface to the action of the acid.

It may be well, perhaps, to say that the plates are now made, not of pure lead, as formerly, but of an alloy, which is harder than lead and stands the work better. The paste, too, which is used to cover the plates is not exactly the same for the two plates of each cell. The positive plate, that is, the plate at which the current enters when the cell is being

charged, is covered with a paste of red lead (Pb_3O_4), and the negative plate with a paste of Litharge, or lead monoxide (PbO). In both cases the oxide is largely converted into sulphate of lead, in the process by which it is prepared; and then, in the charging of the cell, the sulphate of lead is changed into peroxide of lead (PbO_2), on the positive plate, and reduced to the condition of spongy lead on the negative plate.

Difficulty of maintaining Insulation of the Plates.—But even this improved form of cell is not without its faults. It is found that the lead peroxide, however firmly it may be set in the first instance, has a tendency to come off in scales, which fall down to the bottom of the cell. Hence if the lead plates rested on the bottom, a conducting layer of peroxide would, sooner or later, be formed between them, and the insulation of the plates thereby destroyed. This danger has been successfully obviated, by not allowing the plates to rest on the bottom of the cell, but supporting them on ridges of ebonite, or glass, or other insulating material.

Sometimes, however, it will happen that the scales of peroxide, in falling down, get caught between the two plates, and thus form a bridge, which practically destroys the insulation of the plates. There is no way yet known of preventing this evil: but it may be remedied, when it arises, by passing a thin lath of wood, or ebonite, or some such material, between the plates, and setting free the scales of peroxide, which will then fall to the bottom.

Newest Form of Cell.—To facilitate this operation, the plates are now generally placed in glass cells, instead of

wooden boxes; and thus the condition of the plates can be conveniently examined, from time to time, without disturbing them. The adjoining figure, which represents three cells of the Electric Power Storage Company, will give a good idea of the Storage Cells, in their most improved form. It will be observed that each negative plate, marked N, con-

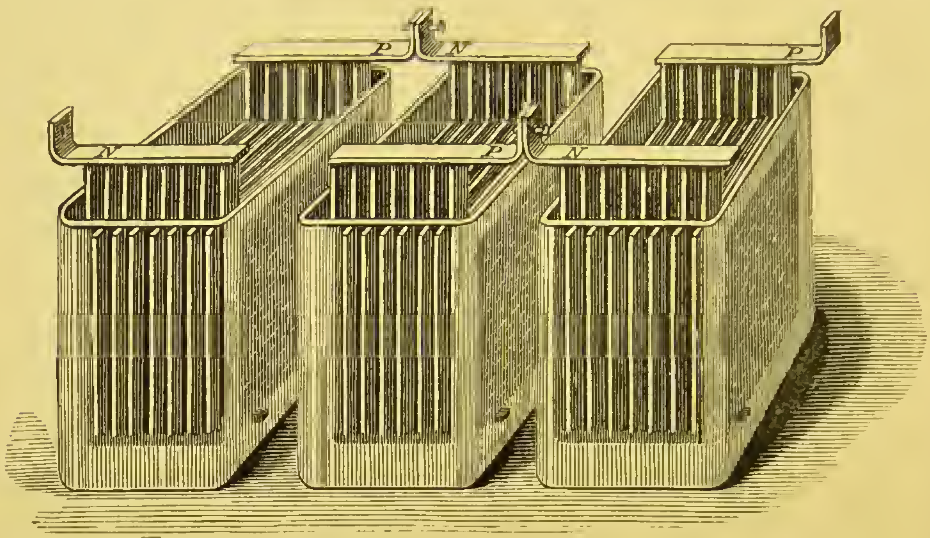

Fig. 30.

Three Storage Cells of the Most Improved Form.

sists of eight separate plates, joined together, at one end, by a thick strip of lead; and that each positive plate, marked P, consists of seven separate plates, similarly joined. Moreover, the negative plate of one cell is connected with the positive plate of the next: this arrangement is known as "arrangement in series," and is the one most commonly used for practical work.

Buckling of the Plates.—Perhaps the most serious difficulty encountered in the use of Storage Batteries is that,

when a cell has been in use for some time, the positive plate shows a tendency to bend, or "buckle," as it is called; and, in this way, it comes into actual contact with the negative plate, thus forming a short circuit through which the cell is discharged. This evil, which is fatal to the usefulness of a cell, is said to be hastened if the Battery is too rapidly charged, or too rapidly discharged, or if the charge is reduced too low, or if the Battery is left too long uncharged. But, even with the greatest care, the evil cannot be altogether prevented; and, after lengthened use, the positive plates will buckle and become useless. How far this fault will eventually interfere with the practical utility of the Storage Battery, it remains for future experience to determine.[1]

Available Energy of a Cell.—There is one respect in which the anticipations, expressed in my Lecture, have not yet been fully realised by experience. In the early days of Accumulators, it was usual to speak of each cell as containing so many foot-pounds of energy; and it was tacitly assumed that this energy was available in whatever way we might please to use it. Thus, for example, a million foot pounds of energy is equivalent to half a horse-power for an hour; and it was assumed that, if we had two cells, each

[1] It is right to notice here that the Electric Power Storage Company have, quite recently, brought out a new type of cell, in which, they say, "the plates are so arranged that there is no possibility of internal short circuits caused by the lodgment of plates or pellets of oxide, or powdered paste, at the bottom of the cells;" and for which they further claim that "internal short-circuiting is impossible." If we may accept these statements literally, and if they be verified when the cell has been subjected to a sufficiently long trial, it would seem that the difficulties described in the text have been, at length, completely overcome.

containing a million foot-pounds of energy, we had practically at our disposal one horse-power for an hour.

But this assumption was soon proved to be inadmissible in practice. First, it was found that we cannot drain off all the energy stored up in a cell, without doing serious injury to the plates. If we wish to keep our Battery in good condition, we must take care only to draw off a certain portion —not more than two-thirds—of the energy it contains. It is usual now to speak of this available portion as the *useful* energy of a cell; and in all practical calculations we should take into account, not the total energy stored up, but only the useful energy.

Again, even as regards the useful energy, we are not at liberty to draw it off at any rate we please. We have learned from experience that, for every storage cell, according to its size, there is a certain maximum rate, at which the energy may be drawn off, in the form of an electric current, without injury to the plates; but if this rate is exceeded, the plates will soon begin to buckle. Thus, for example, in a particular form of cell now made, the useful energy stored up is equivalent to one horse-power for an hour: but we cannot use it *at the rate* of one-horse power, and draw it all off in an hour, without seriously damaging the plates; we can use it at the rate only of one-tenth of a horse-power, drawing it off in ten hours.

These principles, which were not so clearly understood at the date of my Lecture, create some difficulty, no doubt, in the application of storage cells to the driving of tramcars and other vehicles. In the case of a tramcar, for instance, if we want ten-horse power for an hour, to run a double trip of

three miles each way, it is not enough to provide cells with that amount of energy stored up; we must take care first, that the amount of *useful* energy stored up is equal to ten-horse power for an hour, and secondly, that it may be drawn off *at the rate* of ten-horse power, without injury to the plates.

But notwithstanding this difficulty, there seems to be little doubt that, in a few years, storage cells will be very generally employed as the motive power on tramway lines. Already, on the Continent of Europe, tramcars are driven by Accumulators in Brussels, in Hamburg, and in Cologne. Even in England, which is rather behindhand, as compared with other countries, in the practical applications of electricity, there are two lines of tramway worked by Accumulators, one in London, and one in Brighton, each about four miles in length.[1]

Storage Battery for Electric Lighting.—As regards Electric Lighting, the Storage Battery, in its improved form, is now largely used, with great advantage, in the case of small installations. The Battery is placed in the basement story of a house, or in an out-office, and is charged at any convenient time, once or twice, or oftener, in the week, by means of a dynamo, worked by a gas-engine, or a steam-engine, or by water power; and then the lamps may be turned on, at any hour of the night or day, according as they are required. Such a Battery is, no doubt, an expensive element in an Electric Light installation. But it has two great advantages: first, it gives a perfectly steady current, and, therefore, a perfectly steady light; and, secondly, it

[1] See The Electrician, May 25, 1888, page 84.

may be charged at whatever time may be found most convenient, and used whenever it is wanted. I would go so far as to say that, for a small Electric Light installation, especially in a private house, a Storage Battery is not only useful, but practically indispensable.

The case is different, however, when we come to deal with a central station, designed to send out currents for a house-to-house illumination, over a given area. It is sometimes said that great Storage Batteries would be just as necessary, at such a central station, as great gasholders now are at a central gas station. I am not inclined to take this view of the question. If it should be found necessary to store the electrical energy generated at a central station, I think it can be stored more economically at the houses of the consumers, than at the central station itself. For this purpose, it would only be necessary that each house should be provided with a Storage Battery, suitable to its wants; and the Battery could be charged by a current from the central station, whenever required.

But it is by no means certain that a Storage Battery will be found, eventually, a necessary element in the distribution of electric currents, from a central station. Several attempts have already been made, with more or less success, to carry out such a distribution, on a small scale; and in these attempts, so far as I know, the Storage Battery has not been employed. The problem of a house-to-house illumination, on a large scale, has only been taken in hands quite recently; and we have yet to learn from practical experience, the only certain guide in such a matter, in what way it can be carried out, at once most efficiently and most economically.

THE

SUN AS A STOREHOUSE OF ENERGY.

TWO LECTURES

DELIVERED IN THE THEATRE OF THE ROYAL DUBLIN SOCIETY,

APRIL, 1883.

LECTURE I.

THE IMMENSITY OF THE SUN'S ENERGY.

LECTURE II.

THE SOURCE OF THE SUN'S ENERGY.

LECTURE I.

THE IMMENSITY OF THE SUN'S ENERGY.

I PURPOSE, in this Lecture, to give you some practical idea of the vast amount of energy which, in the form of radiant heat and light, the Sun is for ever pouring forth into space. With this object in view, I will ask you to consider the various kinds of energy that exist around us on the earth; and I will try to make clear to you that all these various kinds of energy, with one comparatively trifling exception, have come to us from the Sun. Further, I will show you that the whole of the energy that comes to the earth is only a very small fraction of that which the Sun sends forth. And, lastly, I will explain how the sum total of the energy, going out from the Sun into space, has been measured by scientific men, and I will tell you what it is, when expressed in figures.

The various Forms of Energy available to Man.—It is not difficult to count up the several forms of energy placed at the disposal of man, to do the work of the world. There is, first, water power; next, wind power; third, steam power; fourth, muscular power; fifth, electrical power; and lastly, tidal power. Now it is one of the most interesting, and, at the same time, one of the most certain conclusions of

modern science, that all these various kinds of energy, with the single exception of tidal power, are derived from the energy of the Sun's rays; that they are, in fact, only different forms in which the energy of the Sun is stored up, and made available for our use.

Water Power.—Let us begin with water power. It is the power of falling water; of streams, and rivers, and cataracts. But the water could not fall unless it was first lifted up. The streams and rivers could not flow back to the ocean, unless the water of the ocean had been first carried up to the slopes and summits of the mountains. And you know how this is done. The heat of the Sun, acting on the water of the ocean, converts it into vapour; the vapour expands and rises up into the higher regions of the atmosphere; it is there condensed into clouds; and the clouds, borne about by the winds, pour down rain to feed the rivers and the waterfalls. Thus we may trace back all the water power of the world to the action of the Sun's heat.

But you must not suppose that this colossal work is accomplished without a corresponding expenditure. The heat that lifts up the water of the ocean to the mountain heights is spent on the work that it does. It ceases to exist as heat, and the water power of the world exists in its stead. The energy of the Sun's heat has been converted into the energy of falling water.

I do not mean to dwell at any length on this particular form of energy, which is so familiar to us all. But I would just note, in passing, that although not a single foot-pound of water power is produced, except at the cost of the Sun's energy, yet Nature seems to deal it out to man with the

lavish prodigality of a spendthrift. Let me give you just one example which will help to impress this consideration more distinctly on your minds. The water power of the Falls of Niagara would be more than sufficient to do the work of all the steam engines at present in operation in the whole world. Yet the water power of Niagara is only a small fraction of the water power distributed over the great Continent of North America; and all the water power of North America is again but a fraction of the water power distributed over the earth.

Wind Power.—Next in order comes the power of the wind. It is familiar to everyone in the old-fashioned windmill; and on a larger scale it fills the sails of our merchant ships, and carries a great part of the commerce of the world. But the wind power turned to useful account is, I need hardly tell you, a very small part of that which is placed at our disposal by Nature, and which is ready to do our work, if only we knew how to use it.

Now what is the wind? It is simply the air in motion. And what sets the air in motion? It is the heat that comes to us from the Sun. The earth is heated unequally by the Sun's rays. Within the tropics, where they come down almost vertically, the effect is greatest, and it gradually gets less and less as we go from the tropics towards the Poles. Hence the air near the surface of the earth, within the tropics, being most heated, expands and rises up; then the colder air on each side flows in to take its place, while the heated air above moves off towards the colder regions, north and south. Thus two great currents are established in each hemisphere: a current of cold air below, near the surface of

the earth, flowing from the polar regions towards the Equator; and a current of warm air above, flowing from the Equator towards the Poles. These are the so-called Trade Winds so well known to sailors.

There is a very simple and instructive experiment, by which each one may illustrate for himself the principle of the Trade Winds. Let me suppose that you have two ordinary sitting-rooms, with a door between them; that a fire is burning in one room, no fire in the other; and that a difference of temperature, amounting to five or six degrees centigrade, is thus established between the two rooms. If, under these circumstances, you open the door, and hold a lighted taper in the lower part of the doorway, you will find that the flame of the taper, instead of standing upright, will be bent in towards the room with the fire in it: proving that a steady current of air is flowing in below, from the cold room to the warm room. Next, hold the taper in the upper part of the doorway, and you will find that the flame is bent in the opposite direction, proving that a current of air is flowing out above, from the warm room to the cold room. Now what the fire does for the air of your room the Sun does for the atmosphere within the tropics. And just as the little currents of your experiment are due to the heat of your fire, the energy of the Trade Winds is due to the heat of the Sun.

But there are other winds besides these. Take, for example, the land breeze and the sea breeze, which are found generally to prevail on the sea coast. In the morning, after sunrise, the land is more quickly heated than the sea; the air in contact with the heated surface expands and rises

up, while the cooler air from the sea flows in to take its place. In the evening, on the other hand, the land is more quickly chilled by radiation, when the Sun's heat begins to fail; and, the conditions being reversed, a current of cold air flows back from the land to the sea. Thus the sea breeze of the morning, and the land breeze of the evening, so welcome to yachtsmen along our coasts, derive their existence and their power from the action of the Sun's heat.

This subject is presented very effectively to the imagination by Professor Stokes, in his Burnett Lectures. "When we stand on the coast of the Atlantic, and watch the huge waves which come rolling in and dashing against the rocks in a gale, or it may be as the result of a gale out at sea which never reached us, we are struck by the grand exhibition of mechanical power which we behold. Yet all this power is but a minute fraction of the energy of the Sun's rays which started it; for the waves are due to the long-continued action of the gale on the surface of the ocean, and the gale had its origin in currents of convection which themselves originated in solar radiation."[1]

I need not go further into detail. Enough it is to say, that wherever a breath of wind is moving over the surface of the earth, it is moving from a point of higher atmospheric pressure to a point of lower pressure: the difference of pressure is caused by the expenditure of the Sun's heat; and the lost energy of the Sun's heat re-appears as the energy of the moving air. We may conclude, therefore, that all the wind power of the world, no less than the water

[1] Burnett Lectures, Third Course, pp. 13, 14.

power, owes its existence to the energy that is borne to us by the rays of the Sun.

Steam Power.—We next come to steam power, which, as you know, is obtained by heating water in a closed vessel, called a boiler. I need only remind you that to heat the water we must have a fire; that the heat of the fire is produced by the expenditure of chemical energy in the process of combustion; and that the fuel in which this chemical energy is stored up is, as a general rule, either wood, or turf, or coal. Thus it appears that the energy of steam may be traced back to an energy stored up in our forests, our bogs, and our coal mines. In other words, it may be traced back to the vegetation either of the present age, or of some past age in the world's history; for you know that bogs and coal mines are the remains of ancient forests.

The question then arises, how has this vegetation itself been developed: and the answer is given by the researches of modern science. The plants and trees of our forests spread out their branches, and with their delicate leaves, as with so many fingers, they seize hold of the carbonic acid and the ammonia, which are always present in the atmosphere. More ammonia, together with water and small quantities of certain other substances, are taken in from the soil by the roots, and carried up through the delicate vessels of the plant, in the form of sap.

These all, taken together, constitute the food that supports the life of the plant, and furnishes the material for its growth. And how is that growth developed? By a very interesting and beautiful process. The leaves of plants and trees have the singular power of pulling asunder these

compound substances, of appropriating to themselves the elements that are needed for their growth, and rejecting those that are not needed. Thus they take carbon from the carbonic acid, hydrogen from the water, nitrogen from the ammonia. With these elements, abstracted in this wonderful way from the air and the earth, they build up the structure of their own substance; and in that substance is contained a store of chemical energy, which we turn to useful account whenever we burn wood, or turf, or coal.

There is much that we cannot fully explain in this mysterious process. But one thing is quite certain: that the gathering in of carbon, and hydrogen, and nitrogen, from the air and the earth, is a work that cannot be done without the expenditure of energy. And further, it has been shown, beyond all reasonable doubt, that the energy expended in the operation is the energy of the Sun's rays. That energy is shot out every moment from the Sun; it travels through space with inconceivable velocity for a distance of ninety-two millions of miles, until at length it strikes on the tender leaves of the plant or tree, and there it disappears. It ceases to exist as radiant energy, shooting through space, and it exists henceforth as the stored-up energy of vegetable fibre, until the time for combustion arrives, when a new transformation awaits it.

I have shown you, then, that the energy of steam is generated by the heat of the furnace; and the heat of the furnace is developed by the chemical energy stored up in the fuel; and the chemical energy of the fuel is due to the action of the Sun's rays. It follows, therefore, that steam

power may take its place with water power and wind power, as derived from the energy of the Sun.

Muscular Power.—Next on our list, among the forms of energy available to man, is muscular power. This power is brought into action by the contraction of the muscles; and it is now fully established that whenever a muscle contracts heat is expended. Further, it has been shown that the more work we do by the contraction of a muscle, the more heat we expend: in fact the heat expended is, in point of energy, the exact equivalent of the work done. Animal heat, then, is the immediate source of muscular energy. And the animal heat itself, where does it come from? It is generated within the body by a process of slow combustion. The tissues of our body contain those same compounds of carbon and hydrogen which are found in ordinary fuel; and these tissues are consumed to generate heat in the body, by a process essentially the same as that by which fuel is consumed to generate heat in our fires.

Muscular energy, then, is derived from the chemical energy of combustion; and this energy is stored up in the tissues of our bodies. But where do these tissues come from, which are thus being always consumed and ever renewed again? They are built up, as you know, from the materials supplied by the food we eat. Now if the food be vegetable food, it contains, as we have already seen, the stored-up energy of the Sun's rays. If it be animal food, the animals themselves have derived their substance ultimately from the vegetable world. And so the chain of evidence is complete, which traces back all the muscular power of the world to the energy of the Sun's rays. When

muscular power is exerted, the heat of the body is expended: this heat is produced by a process of slow combustion; the fuel that keeps up the combustion is derived from our food; our food comes directly or indirectly from the vegetable world; and the vegetable world owes its existence to the Sun.

There is one point, connected with this subject, which seems to call for a word of explanation. I have said that, when work is done by muscular power, the heat of the body is expended. Some one may, perhaps, object that if heat is spent in doing work, then, owing to this loss of heat, we ought to feel colder when we do work than when we stand idle; whereas the contrary is shown by experience to be the case. We feel hotter when we do muscular work than when we rest; and the harder we work, the hotter we feel.

To answer this difficulty, I would remind you that, when we do muscular work, the process of slow combustion, which is always going on within us, and by which the heat of our bodies is maintained, is greatly quickened in activity. We breathe more rapidly, taking in larger and more frequent supplies of oxygen. Hence the stores of carbon and hydrogen, which we have already obtained from our food, are more rapidly consumed; and the heat developed by this more rapid consumption of fuel, is not only sufficient to do the muscular work, but to make us feel hotter as well.

I may bring this explanation home to you by a familiar example. A steam-engine is a machine which, like the animal body, does external work by the expenditure of heat. But a steam engine does not get colder when it

begins to do work. And why? Because the stoker, according to his instructions, takes care to add fresh fuel, and to keep his furnace hot when the engine is called upon for work. And so the engine, when doing work and spending heat upon it, actually gets hotter than it was before, in spite of the loss it sustains. Now what the stoker does in the case of the steam engine is accomplished, in the case of the animal body, by a beautiful provision of Nature, whenever muscular work is done.

Electrical Power.—Fifth in order, among the forms of energy at the disposal of man, I have named electrical energy, which seems destined, in the future, to come into common, I might almost say, universal use. I would ask you to observe, however, that electrical power is not given to us ready made by Nature, in a form fit for use, like water power, or wind power, or muscular power. No doubt Nature does give us electrical energy in the lightning flash. But we have not yet learned how to chain the lightning to our will, and make it do our work. Nature, too, gives us electrical energy in what are called *earth currents*. But earth currents will not obey our commands, and chiefly make themselves known by the trouble they give in disturbing the messages that pass through our telegraph wires and submarine cables.

The electrical power which is fit to do our work we have to manufacture, so to say, for ourselves, by means of some other form of power placed at our disposal by Nature. In this respect electricity resembles its great rival, steam. Nature does not give us steam, but she gives us coal, and we make the steam for ourselves by burning the coal in our

furnaces. Let us see, then, what are the means at our command for the production of electrical energy.

Electrical energy, as I am sure you are aware, is now commonly produced by machines in which a coil of copper wire is made to rotate between the poles of a magnet. Now, to make the coil rotate we must use some form of power already at our command—water power, or wind power, or steam power, or muscular power—and the energy expended by the power so employed is converted into the energy of an electric current. But we have already traced back each one of these to the Sun, as its source. And, therefore, the Sun is also the ultimate source of the electrical energy we obtain through them.

If we use a battery, instead of a machine, then the electric current is produced by the slow combustion of zinc: that is to say, the zinc enters into chemical combination with oxygen, in the cells of the battery, and in the process by which they combine, an electric current is produced. Now they could not so combine if they did not first exist apart; and when we seek for the source of energy in a Voltaic battery, we find it in the fact that zinc and oxygen exist apart from each other, with a chemical force between them, tending to make them combine. But they do not exist apart in Nature. In its natural state the metal zinc is always found in chemical combination with oxygen; and before it can become a source of electrical energy the oxygen must be separated from it. This is done by the process of smelting; the smelting is effected by the heat of a furnace; the heat of the furnace is obtained by the combustion of coal; and so we come back to the Sun once more.

Tidal Power.—There is an old adage that the exception confirms the law: *exceptio firmat regulam.* And, like many other old sayings, this adage, under the form of a paradox, contains a germ of solid truth. I believe that we come to realize more thoroughly the full force of a general rule, when we look for exceptions to it, and find how few and scant they are. I have laid it down, as a general rule, that all the working power of the world comes to us from the energy of the Sun; and I have illustrated this general rule by referring to various forms of energy with which every one is familiar. When we come to look for the exceptions, we are told by scientific men that there is really only one exception worth talking of, and that is the power of the tides.

The phenomenon of the tides, as you know, is due chiefly to the attraction of the Moon, though in part also to the attraction of the Sun. Now if the earth were not rotating on its axis, this phenomenon would exist simply as a ridge of water, three or four feet high, on the surface of the ocean, on that side of our globe immediately under the Moon, and another ridge of the same kind on that side of the globe farthest from the Moon. You will see, without any argument, that such a ridge of water would have no more power to do work than a ridge of hill or a railway embankment. What is it, then, that converts this inert phenomenon into a source of power? It is the rotation of the earth on its axis.

As the earth revolves, from West to East, on its axis, the ridge of water remains fixed under the Moon; and thus a relative motion is set up between the tidal ridge and the earth. The effect is practically the same as if the earth were at rest, and the tidal ridge moved, like a great wave, over

the surface of the ocean from East to West. Thus, you see that it is the rotation of the earth on its axis that converts the tidal ridge into a tidal wave, and imparts the energy of motion to an inert mass. The power of the tides, then, is an exception to our general rule : it is derived from the energy of the earth's rotation, and not from the energy of the Sun's rays.

You are aware, I dare say, that the energy of the tides is very little used for practical purposes ; and, therefore, up to the present time, the earth has not been called upon to spend much of its energy of rotation in doing work for man. Nevertheless, I may tell you, that although we do not use the power of the tides, the earth is slowly and surely wearing out its energy of rotation in maintaining that power, and keeping it ready for our use. It is worth while to try and grasp this fact, which is one of great interest.

Figure to yourselves the tidal ridge raised up on the surface of the ocean by the joint attraction of the Sun and Moon ; and remember that, while there is one tidal ridge on that side of the globe which is turned towards the Moon, there is a corresponding ridge on the opposite side, turned away from the Moon. Now as these two ridges remain fixed, the globe revolves between them, thus moving, as it were, between the jaws of a friction break. The friction, no doubt, is slight when compared to the enormous energy of the earth's rotation round its axis. But it is nevertheless real, and is ever at work checking the motion of the earth ; the earth is revolving ever slower and slower ; and if the present order of things lasts long enough, it must eventually stop.

Vastness of the Sun's Energy.—I have now brought before you, in brief review, the various kinds of power available to man—water power, wind power, steam power, muscular power, electrical power, tidal power—and I have shown you that, with the solitary exception of tidal power, they are all derived, directly or indirectly, in the present age or in ages gone by, from the abounding energy of the Sun.

It is difficult to form an adequate conception of the enormous magnitude of the power thus placed at our disposal. We use it, no doubt, and we know, in a general way, that it does the work of the world; but we hardly realize the fact that what we use is only a very minute part, an infinitesimal fraction, of the whole. The rivers flow idle to the sea; the peat bogs are spread out in vain over the surface of the earth; the coal remains pent up within its crust; the winds blow unceasingly over the surface of land and water, and it is only here and there that a solitary windmill spreads out its arms to catch the breeze, or that a white speck on the ocean marks the spot where the swelling sail is speeding before it on its course. Great and wonderful, indeed, is the mechanical work done by man within the present century; but it is altogether insignificant when compared with the boundless wealth of the energies placed at his disposal by Nature.

Now all this boundless wealth of energy, as I have said, with one trifling exception, comes to the earth from the Sun. And what is the earth? A little globular fragment of matter floating in the great ocean of space. The Sun sends forth its rays in all directions, and the earth receives only that small fraction of the whole which is proportional to the

space it occupies. Picture to your minds a hollow sphere corresponding to the orbit of the earth, with the Sun fixed at the centre, and the earth set in the surface of the sphere. The diameter of this spherical shell will be twice the distance of the Sun from the earth, let us say, in round numbers, 184 millions of miles; and the space occupied by the earth will be, of course, a circular area 8,000 miles in diameter. Now it is evident that while the radiant energy, going out from the Sun, falls equally on every part of the surface of the supposed hollow sphere, the earth can receive only that fraction of the whole which falls on the area occupied by itself.

If you calculate at your leisure what that area is, and compare it with the total surface of the sphere, you will find that it is somewhat less than the two-thousand-millionth part of the whole. It follows, therefore, that the earth receives somewhat less than the two-thousand-millionth part of the Sun's rays. In other words, if the radiant energy going out from the Sun, day by day, and year by year, were divided into two thousand million equal parts, that portion which falls to the share of our earth would be somewhat less than one of these parts. And yet the energy that comes to the earth is so vast that we can form no adequate conception of its magnitude. What, then, must we think of the total energy, two thousand million times as great, which goes forth from the Sun into space, and which has been going forth, in the past, not merely during the short span of a few thousand years that covers the period of man's existence, but during the long ages of geological time that preceded the appearance of man upon the earth.

Measurement of the Energy sent out by the Sun.—There is another method by which we may estimate the amount of energy that goes out from the Sun into space. It is the method of actual measurement, first introduced by Pouillet in France, and afterwards adopted by Sir John Herschel, who carried out his experiments at the Cape of Good Hope. The earth, as I have just explained, may be conceived as set in the surface of a hollow sphere 184 millions of miles in diameter, and occupying in that surface a small circular space, of which the diameter is 8,000 miles. Consequently, the earth receives precisely the same amount of radiant energy from the Sun as would fall on this circular area, if the earth were taken away.

Now it is easy to calculate how many square feet are contained in a circular area 8,000 miles in diameter. If, therefore, we could measure the radiant energy that falls, in a given time, on one square foot, we could find, by multiplication, how much would fall, in the same time, on the whole area. This was the problem that Pouillet and Herschel undertook to solve by actual experiment.

Since the Sun is practically at the centre of the hollow sphere, his rays must fall perpendicularly on every part of the surface. Therefore it was necessary to measure the amount of radiant energy that falls on a square foot of surface presented perpendicularly to the path of the Sun's rays. How this was done you will best understand by means of the diagram before you. AB is a shallow cylindrical vessel, made of silver. The upper surface is covered with lampblack, or soot, which has the property of absorbing all the radiant energy that falls on it. The surface of the

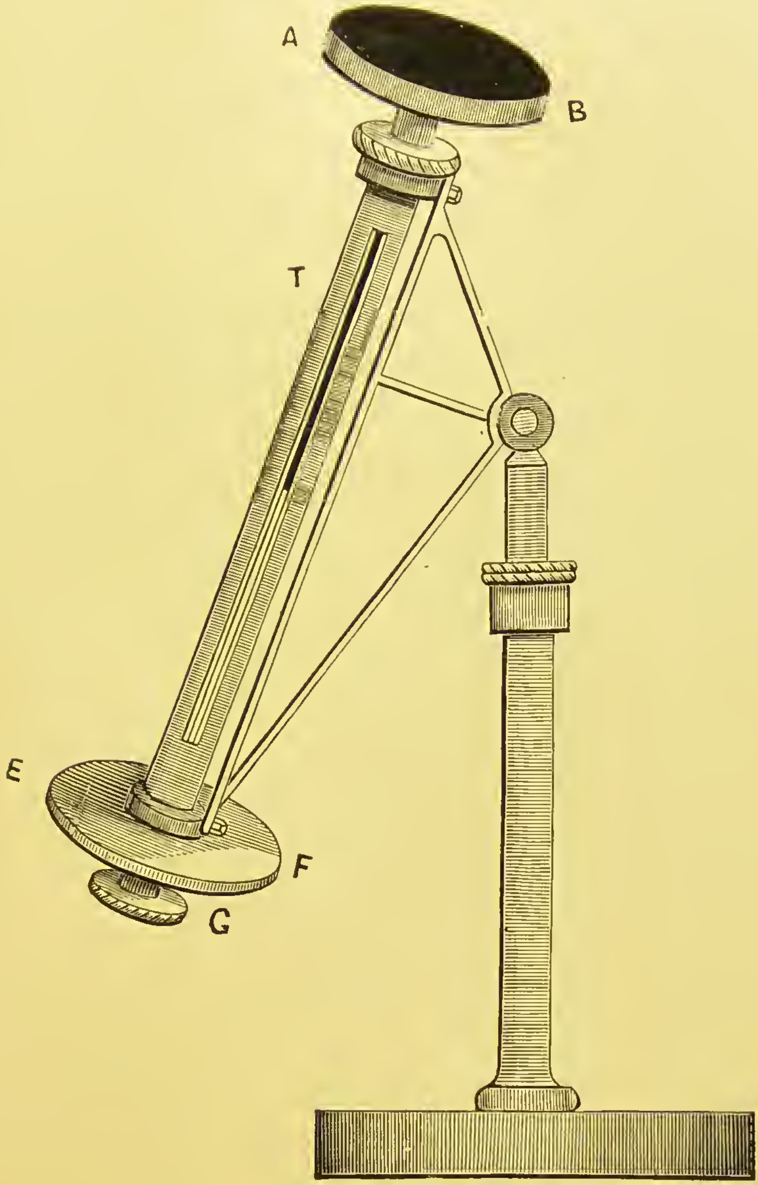

FIG. 31.

POUILLET'S APPARATUS FOR MEASURING THE ENERGY OF SOLAR RADIATION.

A B Shallow Vessel of Silver, partly filled with Water.

T Tube with Thermometer, to indicate Temperature of the Water.

sides and bottom, on the other hand, is highly polished, and has, in consequence, the property of reflecting all the radiant energy that falls on it. The vessel itself is partly filled with water; and in the water is immersed the bulb of a sensitive thermometer, the stem of which projects downwards into the tube T, where you see a black line representing the column of mercury.

The apparatus must now be adjusted, in such a manner that the rays of the Sun shall fall perpendicularly on the upper surface of the shallow vessel. For this purpose it is provided with a universal joint, round which it can be moved at pleasure in any direction; and the adjustment is made by a very simple contrivance. You will observe that the tube T is perpendicular to the upper surface of the vessel AB, and also perpendicular to the disc EF. Therefore when the Sun's rays fall perpendicularly on AB, they will be parallel to T, and the disc EF must be exactly in the shadow of AB. Hence it is only necessary to turn round the apparatus on the joint, until the shadow of AB falls on EF, and then we know that the Sun's rays are perpendicular on AB.

A time is now chosen when the Sun is shining in a perfectly cloudless sky, and the instrument is adjusted in the manner described. Then the vessel is screened for a few minutes from the sun, and the reading of the thermometer is carefully taken. Next, the screen is removed, and the vessel is left exposed to the full energy of the Sun's rays, for a measured time, say for ten minutes. During this time the whole tube is slowly turned round on its axis, by means of the button G, with a view to keep the water gently stirred,

and thus distribute the heat equally to every part of the vessel. At the end of ten minutes the screen is replaced, and the reading of the thermometer taken again. The increase of temperature being thus known, it is easy to calculate how much heat has been added to the vessel and its contents during the ten minutes of its exposure to the Sun's rays.

Corrections.—But this is not enough. Lampblack possesses, in a very high degree, the property of radiating heat, as well as the property of absorbing heat. During the whole time of its exposure, the vessel, while receiving heat from the Sun, was giving out heat of its own; and the addition to its store, at the end of the time, represents only the excess of what it received above what it gave out. It is therefore necessary to measure how much heat it gave out during the time of its exposure. For this purpose it is screened from the Sun's rays, and directed towards a perfectly clear sky. It now radiates heat into space, without any compensation; and the temperature falls. By observing the fall of temperature, in ten minutes, we can calculate the heat lost by radiation in that time; and this, added to the result of our first experiment, will give the total amount of radiant energy that fell on the upper surface of the vessel in ten minutes.

It may be well to observe, in passing, that the Sun's rays, considered in themselves, are all alike in kind, being in fact nothing else than vibrations of the luminiferous ether; but according to the rate of these vibrations, and the nature of the bodies on which they fall, they produce various effects, such as heat, light, and chemical decomposition. In the

experiment before us, however, all the energy of the rays is practically absorbed by the lampblack, and is imparted to the water in the form of heat. Hence the experiment measures, with some degree of rough approximation, the whole energy of the beam that falls on the blackened cover of our cylindrical vessel during the period of its exposure.

Now let me suppose, for the sake of illustration, that the surface of this blackened cover is one square foot. It needs only a sum in multiplication to determine how much radiant energy, at the same rate, would fall every ten minutes on a circular disk, similarly exposed, and 8,000 miles in diameter. And this, as I have told you, is the radiant energy that reaches the earth, every ten minutes, from the Sun.

But I must remind you that a great deal of the energy of the Sun's rays is absorbed by our atmosphere, which extends to a height of many miles ; and it is evident that the Sun should be credited with the heat thus absorbed, no less than with that which reaches the surface of the earth. Pouillet, therefore, made a number of observations, with a view to determine how much of the energy of the Sun's rays is absorbed by the atmosphere of our earth ; and the result of his investigation was to show that the total amount of radiant energy that reaches the outer surface of our atmosphere is about half as much again as that which reaches the surface of the earth.

Practical Estimate of the Energy sent out by the Sun.—The final result thus arrived at might easily be expressed in ordinary heat units, and set down in a long line of figures. But I cannot help thinking that such a row of figures,

however truly it might represent the objective fact, would not much help the mind adequately to conceive or comprehend the fact. Father Secchi, the great Roman astronomer, adopts a better method when he tells us that the heat we receive every year from the Sun would be sufficient to melt a layer of ice somewhat more than 100 feet thick, covering the whole surface of our globe.

But it seemed to me that I could give you a still more practical idea of the vast amount of this energy, if I put it before you in the familiar form of horse-power. Taking, then, the results established by the experiments of Pouillet and Herschel, I find that the energy which comes to the earth with the Sun's rays, day by day, and year by year, would be sufficient to furnish a constant supply of one-third of a horse-power, for every square yard of the earth's surface.[1] Let us try and realize what this means. This hall, in which we are assembed, has a superficial area of about 300 square yards; and one-third of a horse-power for every square yard of the earth's surface would mean, therefore, 100 horse-power for every area on the surface of the earth equal to the floor of this hall; 100 horse-power, for every such area, day and night without ceasing, for thousands and millions of years.

And yet, as we have seen, all this energy, so vast that figures fail to convey an idea of its magnitude, is itself but an insignificant fraction—the two-thousand-millionth part—of the total energy that the Sun sends forth into space. What a wonderful storehouse of energy is here revealed to

[1] See Note at the end of this Lecture, p. 207.

our view. Well may we ask, How is this great storehouse supplied, which thus pours forth its treasures, with lavish prodigality, to the whole universe, and after millions of years shows no signs of exhaustion? This is a question which has given rise to much interesting speculation. It has engaged the attention of some of the greatest scientific minds of the present age; and the results of their investigations I hope to lay before you in my next Lecture.

Note to Page 205.

Estimate of the Energy carried to the Earth by the Sun's Rays.

The calculation referred to in the text, like most others, is best made by adopting the metric system of units. The result of Pouillet's experiments gives us the quantity of heat that would fall, in a minute, on every square metre of the supposed area, 8,000 miles in diameter, as 17·6 kilogramme-centigrade units; each such unit being the quantity of heat that would raise one kilogramme of water through one degree centigrade.[1] But the whole surface of the earth, being four times the surface of a great circle, will be four times that area. Therefore, if the heat coming from the Sun were distributed uniformly over the whole surface of the earth, the amount that would fall on each square metre would be one-fourth of 17·6, or 4·4 kilogramme-centigrade units per minute.

The mechanical energy of one K.-C. unit is 424 kilogrammetres; and therefore the mechanical energy of 4·4 units is $424 \times 4{\cdot}4 = 1865$ kilogrammetres. Now one horse-power is equal to 75 kilogrammetres per second; and, consequently, 1865 kilogrammetres per minute are equal to $\frac{1865}{60 \times 75} = {\cdot}414$ of a horse-power. This is the mechanical energy of the Sun's heat, for every square metre of the earth's surface, on the supposition that it was

[1] See Secchi, Le Soleil, vol. ii. p. 256.

distributed equally over the whole surface. But a square yard is about four-fifths of a square metre; $\frac{\text{square yard}}{\text{square metre}} = \frac{(36^2)}{(40^2)} = \frac{4}{5} = \cdot 8$ nearly; and therefore the mechanical energy for every square yard would be $\cdot 414 \times \cdot 8 = \cdot 33$, or one-third of a horse-power.

Again, 4·4 K.-C. units of heat, per minute, is $4 \cdot 4 \times 60 \times 24 \times 365 = 2,312,640$ units in a year. The latent heat of water being, in round numbers, 80, this quantity of heat would melt $\frac{2,312,640}{80} = 28,908$ kilogrammes of ice. Now if we take the specific gravity of ice as ·9, this quantity would have a volume of $\frac{28,908}{\cdot 9} = 32,120$ cubic decimetres, or about 32 cubic metres; and it would make a column 32 metres high on a base of one square metre. Hence it appears that the radiant energy which reaches the earth every year from the Sun would melt a layer of ice 32 metres high, covering the whole surface of the earth. Thirty-two metres are equal to about 105 feet; and thus we arrive very nearly at the estimate given by Father Secchi.

I should observe, perhaps, that the allowance to be made in these calculations for the absorption of the Sun's rays that takes place in our atmosphere is subject to some uncertainty; and the figures of Pouillet, which I have followed, are those which are least favourable to the Sun's energy. Forbes pointed out, more than forty years ago, certain corrections that should be made in the observations of Pouillet; and making these corrections, he calculated the amount of solar radiation to be about 1·6 times as great as Pouillet's estimate. Again, quite recently in America, Langly carried out very carefully a new series of observations, which make the amount of solar radiation 1·7 times as great as Pouillet had made it.[1]

[1] See Sir William Thomson, On the Sun's Heat, in Good Words, March, 1887, p. 153; also Stokes, Burnett Lectures, Third Course, pp. 9, 10.

LECTURE II.

THE SOURCE OF THE SUN'S ENERGY.

THERE are just two ways in which we may conceive the heat and light of the Sun to be maintained. Either the Sun is a great fire, in which heat and light are developed by combustion, or it is an incandescent mass, like a red-hot ball of iron, which, without being itself consumed, sends out heat and light to surrounding space. If the Sun is a fire, then its store of fuel must be consumed in proportion to the heat produced; and unless new stores be supplied, the fire must eventually go out. If, on the other hand, the Sun is simply an incandescent mass, then it must be always cooling, unless fresh energy is developed within it, and converted into heat.

The Sun not a Great Fire.—Now I may state at once, as the accepted opinion of scientific men, that the Sun is not a great fire in which heat is maintained by combustion; and I will briefly set before you, at the outset, the reasons on which this opinion is based. The burning of coal in an ordinary grate is, I dare say, the form of combustion with which we are most familiar. Let us suppose, then, the Sun to be an enormous globe of coal, burning at the surface. In order to keep the fire alive we must further suppose that the Sun is surrounded by an atmosphere containing a large proportion

of oxygen; for oxygen, as you know, is essential to the process of combustion. But what will happen under these conditions? As the coal burns away, the products of combus-

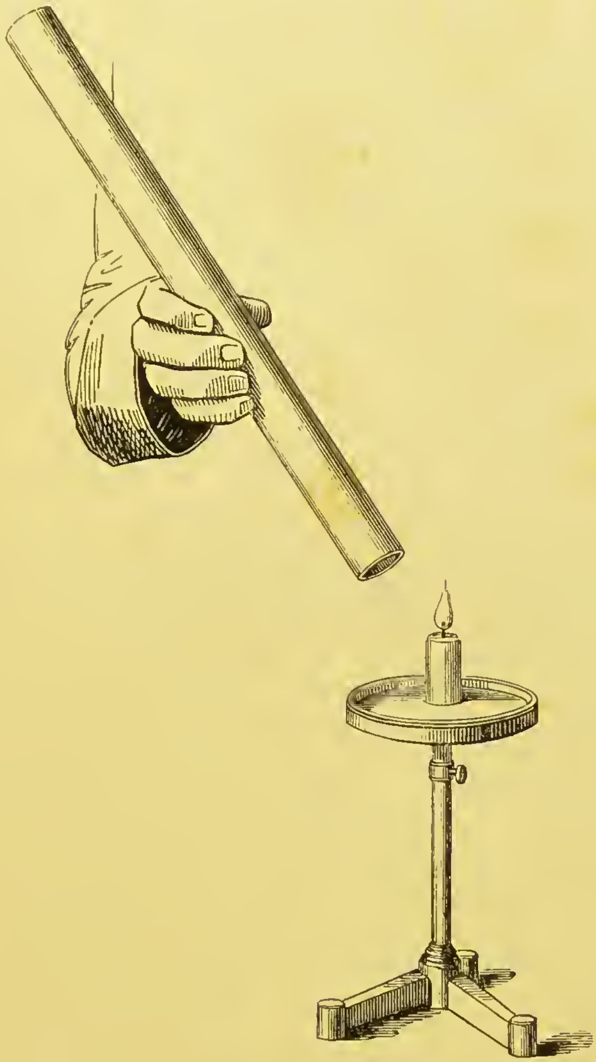

Fig. 32.

Flame Extinguished by the Products of Combustion.

tion pass off, in the form of carbonic acid gas and water vapour; the atmosphere gets choked; the oxygen has no

longer free access to the coal; and the fire must go out in a very short time.

Let me prove this to you by an experiment. Here is a short bit of candle, burning brightly on a stand in the atmosphere of this room. I place over it this large glass tube, which, you will observe, does not shut out the atmosphere, for it is open at the top. You see what happens: in a moment or two the flame gets dim; and now it dies away and goes out.

If I placed a second bit of candle, with a similar tube over it, beside the first, it would meet with the same fate, and so would a third and a fourth. The air of each tube gets choked with the products of combustion, and the oxygen of the atmosphere has no access to the flame. Now, suppose the whole surface of the earth to be covered over with bits of lighted candle placed side by side. It is plain we might dispense with the glass tubes; each lighted candle, by the products of its own combustion, would choke the atmosphere immediately above itself, and all would go out in a few minutes. So too would the Sun be inevitably extinguished, in a very short time, if it were a mass of burning coal surrounded by an atmosphere of oxygen.

But we might suppose the Sun to be made up of some material which should contain within itself all the elements of combustion: that is to say, not only the carbon and the hydrogen, but the oxygen as well. A globe of gun-cotton, for example, would fulfil this condition; and if lighted at its surface might continue to burn away, without any aid from the surrounding atmosphere. But how long would such a globe of burning gun-cotton last, before it would be entirely

consumed? Sir William Thomson has made the calculation very carefully, and has shown that if the Sun were a globe of this kind, giving out heat at the rate it does, it would consume a layer of its substance half a foot thick every minute, or a layer fifty-five miles thick every year.

Now it is in the highest degree improbable, if not altogether inconsistent with observed facts, that the luminous mass of the Sun has been undergoing such a rapid diminution within historic times. Applied to the past, this supposition would mean that 8,000 years ago the Sun was about twice as large as it is now; and, applied to the future, it would mean that in 8,000 years to come the Sun would be completely burned out, and would cease to exist as a source of heat and light.[1]

Perhaps, however, it will be said that fuel may come into the Sun from without, and that, in this way, the fire may be kept up, without any sensible loss to the Sun itself. This supposition is quite possible, and, to some extent, I would even say it is highly probable. We know, as a fact, that certain meteoric bodies, called *falling stars*, sometimes fall down on the earth from planetary space, and blaze up into heat and light at the moment of their fall. It is therefore probable that such bodies also, from time to time, fall into the Sun; and with the high temperature of the Sun, it is inevitable that combustion must take place, if a sufficient supply of oxygen is near at hand.

But the heat due to the combustion of meteoric bodies is hardly worth taking into account as a source of solar energy; for it can be shown by exact calculation, and I will take occa-

[1] See Philosophical Magazine, vol. viii., 1854, p. 417.

sion, by-and-by, to give you some idea of how this calculation has been made, that the heat produced by the combustion of any meteoric body, moving through space, is indefinitely small when compared to the heat that must be produced by the mere fact of its collision with the Sun. So far as our experience goes, these meteoric bodies are composed mainly of iron; and it has been shown that a mass of iron falling into the Sun would, by the fact of its fall, generate 18,000 times as much heat as would be produced by the combustion of the same mass in an atmosphere of oxygen. Even if we take the more favourable supposition that the fuel falling into the Sun consisted entirely of the best coal, the heat due to its fall would be at least 3,000 times greater than the heat due to its combustion.[1]

I do not deny, then, that the process of combustion may go on, to some extent, at the surface of the Sun. But I say that combustion cannot be regarded as the chief source, or even a very considerable source, of the Sun's heat. Not the combustion of the Sun itself; for this supposition would involve changes in the Sun's mass, within historic times, which seem altogether inadmissible. Not the combustion of fuel coming in from without; because such fuel, by the simple fact of its collision with the Sun, would generate several thousand times more heat than it could possibly generate by its combustion.

The Sun an Incandescent Mass.—We are thus led to regard the Sun not as a mass of burning fuel, like a great furnace, but rather as a globe of incandescent matter, like

[1] See Philosophical Magazine, vol. viii., 1854, p. 418; also Secchi, Le Soleil, tome ii. pp. 267, 268.

a red-hot ball of iron, which, without being itself consumed, sends forth heat and light into space. But an incandescent mass of this kind, always losing heat by radiation, must inevitably cool down, until it is reduced to the temperature of surrounding space, if more heat is not developed within it by the expenditure of some other form of energy. Now, we have every reason to believe that the Sun is not cooling down in this manner; that it is, in fact, as rich a source of heat and light at this moment as it was 6,000 years ago. And the question arises, Where is the store of energy which has been able to maintain this heat and light, during that long period of time, notwithstanding the vast expenditure going on, and which still maintains it, without any signs of exhaustion or decay?

To this question two answers have been given, which are eminently worthy of consideration, as well for their intrinsic importance as for the distinguished names with which they are associated. One is the answer of Sir William Thomson, who has suggested that the chief source of solar energy is to be found in the collision of meteoric bodies with the Sun. The other is the answer of Professor Helmholtz, of Berlin, who maintains that the Sun's heat is mainly due to the gradual compression of its mass under the influence of gravitation.

Before proceeding to discuss these theories, perhaps I ought to say that we are here passing beyond the bounds of established scientific truth, and entering on the region of speculation. In my last Lecture, when speaking of the immensity of the Sun's energy, I was dealing mainly with demonstrated facts. I was able to show you, by a train of

perfectly conclusive reasoning, that, practically, all the energy available to man to do the work of the world may be traced back to its source in the energy of the Sun's rays; and, with the knowledge derived from actual experiment, we were able to measure roughly the absolute quantity of energy thus sent forth from the Sun, and borne through the universe on the swift wings of radiant heat and light.

But when we come to consider how this energy is itself developed within the Sun, we are left very much to speculation and conjecture—conjecture, no doubt, resting on the basis of scientific knowledge, but not yet capable of rigorous demonstration. I would say, then, that in following out this question we are somewhat in the condition of travellers who have reached the boundary line that separates the known country from the unknown; and we are now about to cross that line, and enter into a new region of scientific inquiry, following in the track of a few adventurous and illustrious explorers.

Incandescence and Combustion.—In the first place, let me try to make quite clear what I mean by an incandescent mass, as distinguished from a mass of burning fuel; for this distinction lies at the very foundation of the problem we have to consider. When a body is made hot by being burned, it is consumed in the process; but when a body is kept in a state of incandescence, without being burned, then it is not consumed, but remains the same in its mass, the same in its chemical composition, as it was before. If you burn a bag of coals in a grate, I need not tell you that, when your fire is out, your bag of coals is gone. But if you make a ball of iron white hot, in a furnace, the ball of iron is not consumed,

though it becomes itself a source of heat and light; and when it cools down again it is exactly what it was before.

The incandescent mass, however, must derive its heat from some existing store of energy. Though it is not consumed itself, something must be consumed in order to produce the heat that is sent forth into space. This is a point of primary importance, which I should wish to impress upon you by one or two familiar illustrations. In the example just given, the furnace is the store of energy; and the iron ball, put into the furnace, simply gets a portion of the store, and is thus made hot without being consumed. But the store of energy may exist in other forms. You know, I dare say, that a smith, by repeated blows of his hammer, can make a bar of iron red hot on the anvil. In this case, the bar of iron is not consumed, but the muscular energy of the smith is consumed; and, moreover, the energy of the heat produced is the exact equivalent of the muscular energy expended in producing it. Now, the glowing bar of iron sends out rays of heat and light into surrounding space; and if this loss is not made good, if the smith pauses in his work, even for a few moments, the bar will cease to glow. Thus we learn that a constant supply of new energy is absolutely necessary to maintain a body in a state of incandescence.

The electric current furnishes another and a very instructive illustration. When I send a strong current through this spiral of platinum wire, the metal glows with intense heat, but it is not consumed. The heat, as you know, is maintained at the cost of the electric current. At the present moment, the current passing through the wire generates, in each unit of time, just as much heat as the wire, in that time,

sends forth into space; and so the spiral continues to glow, emitting a perfectly steady stream of radiant heat and light. If I cut off the current, the wire goes on, for a brief space, shining as before. But it is now expending its little stock of heat, without receiving any fresh energy to renew the store. In a moment or two it ceases to shine, and in a few seconds more it is as cold as the objects around.

I think you will now clearly understand the problem with which we have to deal. Not more surely does the glowing bar of iron cease to glow, when the blows of the hammer are suspended, not more surely does this little platinum spiral cease to shine, when the electric current is stopped, than the Sun itself would be extinguished if there were not at hand some prodigious source of energy, to make good the vast expenditure that is for ever going on. And the question is, Where is this source of energy to be found?

Meteoric Theory of Sir William Thomson.—In the year 1854, Sir William Thomson read a Paper on the Mechanical Energy of the Solar System, before the Royal Society of Edinburgh, in which he put forward and supported his theory, that the main source of Solar energy is to be found in the collision of meteoric bodies with the Sun.[1] You know that, when a rifle bullet strikes a target, the energy of its motion is at once converted into heat. Imagine, then, a

[1] See Transactions of the Royal Society of Edinburgh, 1854; also Philosophical Magazine, 1854. It is right to state that this theory of the Sun's heat was set forth, with great completeness, by Mayer of Heilbronn, in 1848, in a memoir entitled, "Beiträge zur Dynamik des Himmels." Five years later, it was sketched out independently by Mr. Waterston, at the meeting of the British Association, at Hull. But it was more elaborately worked out by Sir William Thomson, who professedly took the leading idea from Mr. Waterston's Paper, but apparently was unacquainted, at the time, with Mayer's work.

target exposed to a perpetual shower of bullets striking against it at every moment. You can easily understand how it might be kept red hot by the impact of the bullets, just as the bar of iron, referred to in a previous illustration, is kept red hot by the blows of the smith's hammer. Now, Sir William Thomson supposed that the Sun is somewhat in the condition of such a target: that it is pelted unceasingly by small meteoric bodies falling into the mass; and that the heat generated by this incessant hammering is sufficient to cover the expenditure going on at its surface.

Let me give you a brief account of these meteoric bodies, so far as we know them actually to exist in the Solar System. Everyone is familiar with the phenomenon known by the name of *falling stars*. Generally these falling stars are seen only one at a time; but sometimes they come in groups; and on certain rare occasions—once in about every thirty-three years—they come as a perfect shower of fiery balls, shooting through our atmosphere for several hours together. A splendid display of this kind took place on the night of November 13, 1866, and was probably seen by many who are here present. The fiery shower began with a few stray balls, about half-past ten; then they came in twos and threes; and the number went on increasing up to one o'clock, when they came, for some time, at the rate of about one every second. At that hour the spectacle was, indeed, magnificent and impressive. After this, the number gradually diminished, and at half-past four in the morning the display was at an end.

These so-called falling stars are nothing more than masses of solid matter, revolving in orbits round the sun, just as the planets do, and often moving with a velocity of from

twenty to thirty miles a second. When they come across the earth's path, they are raised to a very high temperature, partly by friction with our atmosphere, partly by the compression of the air in front of them, and they suddenly become brilliantly incandescent. Sometimes, when they come near enough, they are drawn out of their course by the attraction of the earth, and fall to the ground. They have often been picked up by those who have seen them fall; and you may see specimens of them, under the name of *meteoric stones*, in almost any large collection of minerals. They are found to consist chiefly of iron; but many other elements, such as copper, tin, nickel, cobalt, also potash, soda, magnesia, lime, silica, enter more or less into their compositions. It is remarkable that not a single element has yet been discovered in any of these meteoric stones with which we are not familiar among the materials of our own planet.

Some of you, perhaps, may find it difficult to believe that a cold mass of iron should be converted into a brilliantly luminous meteor, simply by moving through our atmosphere. We have no example in every-day life of such intense heat produced by the friction of a gas against a solid body. Nevertheless, I think I can make this point quite clear to you by a simple illustration. It is a fact of ordinary experience, in practice with large guns, that when a cannon ball strikes against a plate of iron armour, and its motion is thus suddenly arrested, it becomes intensely heated, and a flash of light is often seen to issue from it at the moment of collision. Now the heat developed in this case is entirely due to the motion that has been destroyed. The energy of motion is converted by the collision into the energy of heat.

To put this conception into a definite form, let me suppose that a ball of iron, one pound in weight, strikes against an iron target with a velocity of 1,600 feet a second. It is easy to calculate, with perfect scientific accuracy, the amount of heat that is generated at the moment of collision. Without going into the calculation, I may tell you that the heat would be just sufficient to raise a pound weight of water through 29 degrees of the Centigrade scale, or to raise a pound weight of iron through 240 degrees of the Centigrade scale.[1] Of course, a part only of that heat is developed in the iron ball, and a part is developed in the target that stops its motion. If we suppose the total heat generated to be divided equally between the two, then the iron ball would be raised by the collision through 120 degrees of the Centigrade scale. Observe, this is the effect produced when an iron ball, one pound in weight, is arrested in its course, and loses a velocity of 1,600 feet a second.

Let us now consider the case of a meteoric mass of iron, one pound in weight, moving through space with a velocity of 20 miles a second. When it enters our atmosphere, its motion is obstructed by friction; and I think you will not regard me as extravagant if I suppose that, in passing through, it may easily lose, on the whole, one-fifth of its initial velocity. Thus we have a pound weight of matter entering our atmosphere with a velocity of 20 miles a second, and leaving it with a velocity of 16 miles a second, having lost, in its passage, a velocity of 4 miles a second. Now, the energy of the motion destroyed has been all converted into heat; and it can be shown that the total heat developed is

[1] See Note I. at the end of this Lecture, p. 232.

more than fifteen hundred times as great as when an iron ball, of equal mass, strikes against a target with a velocity of 1,600 feet a second.[1] No doubt, a great part of this heat goes to raise the temperature of the atmosphere. But you will easily see that even a fraction of it would be sufficient to raise the meteoric mass itself to incandescence, and to keep it incandescent during the brief time of its passage.

The existence, then, of meteoric bodies, moving through space, is an established fact. That heat is generated whenever the motion of such bodies is retarded or destroyed is also an established fact, and one that can be fully accounted for on scientific principles. Now, Sir William Thomson showed that bodies of this kind, revolving round the Sun, will gradually be drawn in by the force of gravitation, and eventually fall down on his surface. Hence, he said, we are justified in supposing that there is a perpetual rain of meteors into the Sun; and he calculated that the velocity due to their fall cannot be less than 270 miles a second. But the whole of this velocity must be destroyed before they come to rest on the surface of the Sun; and the energy of motion thus extinguished from day to day, on a scale of colossal magnitude, may be regarded as the chief source from which the heat of the Sun is derived.

It may be objected, perhaps, that, according to this theory, the Sun must, every year, be getting larger and larger, by the accession of fresh matter from without; and yet no sensible increase of size has been apparent, during the long period within which it has been the object of close and careful observation. This difficulty did not escape the keen

[1] See Note II. at the end of this Lecture, p. 233.

glance of Sir William Thomson. With a view to estimate the true value of the argument, he calculated, in the first place, how much matter should fall into the Sun every year, in order to cover the expenditure of heat due to radiation, and he found it to be about 3,800 pounds weight for every square foot of the Sun's surface. Now the mean density of the Sun is about equal to the mean density of water; and if we suppose the falling meteors to have the same density as water, 3,800 pounds weight on every square foot would form a layer of matter 60 feet deep over the whole surface of the Sun.

On this supposition, then, the diameter of the Sun would be increased by twice 60 feet, that is 120 feet, every year, or about a mile in 44 years. At such a rate, the total increase of the Sun's diameter, during a period of 6,000 years, would be less than 140 miles.[1] Now 140 miles is only the $\frac{1}{6000}$ part of the Sun's actual diameter; and so small an increase, even if it took place entirely within the present century, instead of being spread over 6,000 years, could hardly have been detected with all the refined appliances of modern science. We may, therefore, feel quite confident that all the heat sent forth by the Sun, within historic times, might have been developed by the falling of meteors into his mass, and yet that the increase of his bulk produced thereby would have escaped the closest observation possible to man during that time.

Such is the Meteoric Theory by which, thirty years ago,

[1] A cubic foot of water weighs, in round numbers, 62·5 pounds. Therefore 3,800 pounds weight of water would have a volume of $\frac{3,800}{62 \cdot 5}$, or about 60 cubic feet, and would make a column 60 feet high, and one square foot in cross section. The diameter of the Sun would thus be increased by 120 feet a-year; and in 6,000 years, by $120 \times 6,000 = 720,000$ feet, or $\frac{720,000}{1,760 \times 3} = 140$ miles.

Sir William Thomson sought to account for the origin of the Sun's heat. I have thought it right to set it forth with some degree of completeness, both on account of its intrinsic interest, and of the important place it holds in the history of the question before us. But I may now say that it is open to objections, from an astronomical point of view, which seem practically insurmountable. If this enormous mass of meteors fell into the Sun from the outer regions of the Solar system, they would produce such a disturbance in the path of the earth, and of the inferior planets, as could not fail to be detected. And if, on the other hand, in order to avoid this difficulty, we conceive them to exist as a dense cloud of matter close to the Sun, they must have been encountered by certain comets which are known to have passed through that region, and which would have been sensibly retarded in their course by the action of so great a mass: yet these comets pursued their career undisturbed, and showed no signs of any such encounter.

Chiefly for these reasons, the Meteoric Theory has been generally abandoned by scientific men, and is now practically given up by Sir William Thomson himself. He maintains, indeed, and justly maintains, that meteoric bodies fall into the Sun from time to time, and that, falling in, they contribute, in some measure, to the development of Solar heat. But all things considered, he says, their effect must be almost inappreciable, when compared to the vast expenditure of heat that is daily going on.[1]

[1] See short Paper by Sir William Thomson in Macmillan's Magazine, vol. v. p. 389; also another Paper in Good Words, March, 1887, p. 150. See also Secchi, Le Soleil, vol. ii. p. 269; Newcomb, Popular Astronomy, p. 521; Sir Robert Ball, The Story of the Heavens, Second Edition, pp. 499–501.

Compression Theory of Professor Helmholtz.—Nevertheless this theory, though admittedly insufficient to furnish a complete account of the source from which the Sun's energy is derived, has done a great and important service. It has fixed the attention of scientific men on the force of gravitation, as a force existing within the Sun itself, which is capable of producing heat and light. This is the fundamental idea of the Meteoric Theory. The attraction of gravitation pulls into the mass of the Sun a vast cloud of meteoric bodies which had been previously flying through space; it pulls them with enormous force, and by actual collision the energy of the moving meteors is converted into the energy of heat.

Now, I have said that the great multitude of meteoric bodies, which this theory supposes to be always falling into the Sun, cannot be admitted to exist. But the fact is, they are not wanted. The force of gravitation is just as competent to develop heat, by acting on the Sun's own mass, and pulling that mass together, towards a central point within it, as by acting on a cloud of meteors, and pulling them towards the centre of the Sun. This is the simple and beautiful theory of Helmholtz, to which I would now ask your attention.

That the Sun is at present undergoing a process of condensation seems in the highest degree probable. We know, from the revelations of the Spectroscope, that the Sun is composed, in the main, of the same elements as the earth; and yet the mean density of the Sun is only one-fourth of the mean density of the earth. In other words, the same kind of matter is found to exist in the Sun as in the earth;

but in the Sun it exists in a far more scattered and loosely compacted condition.

This fact is the more striking when we remember that the force of gravitation, which tends to pull that mass together, is twenty-seven times as great in the Sun as it is in the earth. The mass of matter which we call a pound weight, if transported to the Sun, would require the same effort to lift it up as twenty-seven pounds would require at the surface of the earth. A man placed on the surface of the Sun would weigh as much as twenty-seven men on the surface of the earth. If lying down, he could not, by any effort, lift himself up; he would simply be crushed against the surface of the Sun by the force of his own weight.

How is it then, that, notwithstanding this enormous compressing force, the matter of the Sun is so much less closely compacted together than the matter of the earth? The answer is to be found in the high temperature of the Sun. Heat tends to make matter expand, and the great heat of the Sun develops a powerful expansive force, which resists compression. Thus we may conceive the mass of the Sun, at any moment, as subject to the influence of two opposing forces: one due to heat, which tends to make it expand; the other, the force of gravitation, which tends to make it contract.

If these two forces remained without any change, a condition of equilibrium would be established and maintained between them. But the balance is being always disturbed, and then again restored. Heat passes off by radiation; the expansive force due to heat is thus diminished; gravitation then prevails, and condensation follows. But

condensation develops more heat. You are familiar, I am sure, with examples of this well-known law. If I condense air in the barrel of an air-gun, I feel the barrel get sensibly hot in my hand: so, too, the Sun gets hotter when it is compressed by the enormous force of gravitation; and thus the heat lost by radiation is restored by compression. Then more heat passes off; further compression follows, and the loss is again made good. Thus it would seem that so long as the loss of heat by radiation is followed by further compression, the store of heat in the Sun may be kept ever renewed, and suffer no diminution.[1]

How long, then, it will be asked, may this process be expected to go on? This is a question that cannot be answered with any degree of precision. There is, indeed, good reason to believe that the Sun will continue to get more and more compressed, until its mean density is greater than that of the earth; for the materials are the same, and the compressing force, which is the force of gravitation, is much greater in the case of the Sun than in the case of the earth. But taking the more moderate assumption, that the process of compression will go on until the density of the Sun is, at least, equal to the density of the earth—that is to say, until the Sun is reduced to one-fourth of its present size—Helmholtz has shown that the heat developed by such a condensation would be sufficient to maintain the expenditure, at the present rate, for seventeen millions of years yet to come.[2]

Of course, if we accept this theory, we must be prepared

[1] See Newcomb's Popular Astronomy, Second Edition, p. 522; Sir Robert Ball's Story of the Heavens, Second Edition, pp. 501–3.

[2] Populäre wissenschaftliche Vorträge, von H. Helmholtz, Drittes Heft, Braunschweig, 1876, pp. 128–9.

to admit that the Sun is getting smaller and smaller, from year to year. But this admission involves no special difficulty. According to a calculation made by Helmholtz, it appears that a contraction of the Sun's mass, such as would reduce his diameter by the ten-thousandth part of its present length, would generate heat enough to cover the expenditure for a period of 2,000 years.[1] A change so small as this, it is hardly necessary to say, would have been quite insensible within the period of human history.

Bearing of the Nebular Hypothesis.—This theory, then, considered on its own merits, seems to offer a complete and perfectly sufficient account of the origin of Solar heat. But there is another consideration in its favour, which I ought not altogether to omit. You are acquainted, I am sure, with the nebular hypothesis, which has been making its way, for a long time, among astronomers, and which is supported by various kinds of evidence quite independent of our investigation to-day.

According to this hypothesis, the Sun is nothing more nor less than a condensed nebula, or mass of vapour. In its primeval condition this nebula, which contained, in an extremely attenuated form, all the elements of which the Sun and planets, with their satellites, are now composed, extended as far, at least, as the orbit of the most distant planet. It possessed a slow motion of rotation, and was endowed with a force of gravitation, which tended to pull the whole mass

[1] Populäre wissenschaftliche Vorträge, von H. Helmholtz, Drittes Heft. Braunschweig, 1876, pp. 128–9, Zweites Heft, p. 131. See also Thomson and Tait, Treatise on Natural Philosophy, vol. i., part ii., p. 489; Newcomb, Popular Astronomy, p. 521; and Ball, Story of the Heavens, Second Edition, pp. 501–4.

together towards a central point within it. As it was gradually condensed, its motion of rotation became more rapid, according to a well-established law. From time to time, fragments were cast off, at the outer surface, and began to be condensed, each one round a centre within itself. These fragments, after separation, all retained their former motion, and thus went on revolving round the central mass, which was ever getting smaller and smaller. In some cases the fragments themselves cast off lesser fragments, which, by the same law, went on revolving round the fragments from which they had come; and, of course, they too began to be condensed, each one round a centre within itself. Thus, in the lapse of time, the great central mass was condensed into a Sun; and the fragments were condensed into planets, revolving round the Sun; and the fragments of the fragments were condensed into satellites, revolving round the planets.

It is not my purpose to enter into this great and comprehensive theory; much less to set before you the evidence on which it is founded. I will only say, what you must all see at once, that if this theory be admitted, the problem of the Sun's heat is already solved. The orbit of Neptune, the outermost of the known planets, may be regarded as a circle of which the diameter is about 5,000 millions of miles. According to the nebular hypothesis, the Sun was once a great mass of vapour, filling the whole space enclosed within that orbit; and the compression of such a mass of vapour into the present volume of the Sun would generate heat enough, as Helmholtz has shown, to cover the vast expenditure now going on, for a period of twenty millions of years.

This, I think, will be found amply sufficient to satisfy

all the reasonable demands of geological science, in the matter of time past. Then, as regards the future, we have seen that the further condensation of the Sun, until his density would be reduced to the density of the earth, would yield heat enough to maintain the present expenditure for seventeen millions of years yet to come.

But I do not want you to accept the nebular theory as an established scientific truth. My case is simply this. From the present physical condition of the Sun, we have been led to infer, as probable, that it is undergoing a process of condensation, and that this condensation is the source from which its heat is derived. We then find that, on purely astronomical grounds, the Sun, as it now exists, is supposed to have been compacted together from a primeval nebula, by a process of gradual condensation. This view was suggested to La Place by his profound study of the dynamical laws that control the Solar system; it grew up in the mind of Sir William Herschel, from his long and patient observation of the heavens with the aid of his great telescope; it is adopted by Secchi, who writes with all the light that recent researches have thrown on the subject. We take it then as it comes to us, commended by the greatest astronomers of the age, and we say that it strongly tends to confirm the conclusion at which we ourselves had arrived by a different line of reasoning. If it be true that the Sun has reached its present condition by a process of condensation, in which an enormous quantity of heat must inevitably have been developed, then it is all the more reasonable to suppose that the process of condensation is going on at present, and that fresh supplies of heat are generated by it from day to day.

The Past Energy of the Sun.—And now, having gone so far in our speculations, it is almost impossible not to go one step further, and to ask the question, What has become of that vast quantity of energy which has gone forth from the Sun during the long ages of past time? You might suppose, perhaps, that it has ceased to exist. But such a supposition would be entirely gratuitous, and certainly would find no countenance from scientific men. We have a great and varied experience of energy, both in practical life and in scientific investigations, but not one single example of the annihilation of energy has ever yet been established.

Well, then, perhaps the radiant energy of the Sun, if it has not been destroyed, has been used to do work in some distant part of the universe, and has thus been converted into other forms of energy. But what work can it do in empty space? And, except for a few stray beams that impinge, here and there, on a fixed star, or a comet, or a nebula, all the radiant heat of the Sun, so far as we know, passes through empty space. Perhaps, then, you will take refuge in the ingenious theory propounded last year by Sir William Siemens, who imagined that the radiant energy of the Sun is gathered up, in distant space, by some mechanical process, and carried back to the Sun from whence it came. But the theory of Sir William Siemens has not yet received the stamp of general scientific approval, and seems to many persons directly at variance with mechanical laws.

On the whole, it is, perhaps, most probable that this radiant energy has neither been annihilated, nor converted into work, nor gathered up and carried back to the Sun, but is still pursuing its course through space. This supposition

is quite in accord with the analogy of established facts. You know that there are stars in the heavens so distant that the light by which they are now visible to us, the light that enters our telescopes, night after night, and announces to us their existence in far off space, has been thousands of years on its journey hither. May we not suppose, then, with some reason, that the light which went out, some thousands of years ago, from the Sun, which is the fixed star of our system, is, in like manner, still pursuing its career in distant space?

It is worth while trying to realize what is involved in this supposition. Let me give you just one illustration. About two thousand years ago, all the valour of the Roman arms was gathered together, on the plains of Pharsalia, to contend for the empire of the world. The rays of the Sun fell on the battle-field, and were reflected from helmet and shield and spear. And ever since that eventful day, these rays have been speeding away through space, with a velocity of 180,000 miles a second. Now, if we suppose a being gifted with eyesight so keen that he could see the most distant object by the aid of the faintest light, and endowed with a speed so swift that he could traverse the universe at a bound, such a being need but place himself to-day in the path of these rays at a point probably much nearer to us than many of the fixed stars, and looking down on the plains of Pharsalia he could see the battle going on.

Summary.—I will now sum up, in a few words, the general heads of the discussion through which I have conducted you, and the results at which we have arrived. In my first Lecture I asked you to consider the various forms of energy existing

around us on the earth; and I showed you that, with one comparatively trifling exception, they may all be traced to the energy that comes to us from the Sun. The energy of the Sun lifts up the waters of the ocean to the summits of the mountains, and leaves them to flow back in the form of streams and rivers, of cataracts and torrents. The energy of the Sun has lain for ages stored up in our coal mines; and it is given out again when we light our fires. It is heard in the roaring of the wind; it is seen in the dazzling beams of the electric light. In the form of muscular energy it takes part in all our small industries; and in the form of high pressure steam it drives our machinery and carries the commerce of the world.

Next I sought to impress on you the very obvious fact that the sum total of all the energy that has reached the earth, from primeval times to the present, is only an infinitesimal fraction of the energy that has gone forth from the Sun into space. But this great expenditure requires a supply of commensurate magnitude. The Sun could not always go on pouring out heat and light into space, with lavish prodigality, as he does, unless fresh heat is supplied from without or developed from within. Thus arose the question, how is the Sun's heat maintained. And this was the subject of my Lecture to-day.

When the question was fully before us, and the problem distinctly stated, we saw without much difficulty that the Sun's heat is not maintained, to any great extent, by combustion; for if the Sun were a mass of burning matter, that is to say, if it were simply a large fire, it would have been burned out long ago. Neither can the main supply of solar

heat be ascribed to the falling in of meteors. It is highly probable, indeed, that meteoric bodies do fall into the Sun; and it is quite certain that, when they fall in, they must contribute, in some measure, to his store of heat. But astronomical considerations seem clearly to show that the quantity of such bodies falling into the Sun, within historic times, cannot be sufficient to cover the expenditure of heat that is actually going on.

We then came to the theory of Helmholtz: that the Sun is undergoing a process of condensation; that the condensing force is gravitation, which tends to pull the mass together towards a central point within it; and that the effect of condensation is the development of heat. This theory, I have tried to show you, is entirely in harmony with the principles of science, while it furnishes a sufficient account of the origin of solar heat; and though it cannot claim to be regarded as an established truth, it may fairly be accepted as a well-founded hypothesis.

Note I.

The Energy of a Moving Mass in Heat Units.[1]

The energy of a moving mass, in absolute units, is equal to half the mass multiplied by the square of the velocity, or, as it is commonly written, $\frac{mv^2}{2}$. This gives us, in the case under consideration, the mass being one pound, and the velocity 1,600 feet a second, $\frac{(1,600)^2}{2}$, or 1,280,000 absolute units of energy. To reduce absolute units of energy to gravitation units, or foot-pounds, we must divide by the force of gravity, which in the British system of units is, in round numbers, 32. Thus it appears that the energy of the moving mass is $\frac{1,280,000}{32}$

[1] See page 219.

= 40,000 foot-pounds. Now it has been shown by Joule that 1,390 foot-pounds of energy, when converted into heat, would be just sufficient to raise a pound weight of water through one degree of the Centigrade scale; therefore 40,000 foot-pounds would be just sufficient to raise a pound weight of water through $\frac{40,000}{1,390}$, or about 29 degrees of the Centigrade scale. Lastly, the heat that would raise a pound weight of water one degree would raise a pound weight of iron 8·3 degrees; and therefore the 40,000 foot-pounds of energy, converted into heat, would raise a pound weight of iron through 29 × 8·3, or about 240 degrees.

NOTE II.

THE HEAT DEVELOPED BY A METEOR PASSING THROUGH THE EARTH'S ATMOSPHERE.[1]

If we suppose a meteoric mass, one pound in weight, to have its velocity reduced from 20 miles a second to 16 miles a second, in passing through our atmosphere, its energy of motion will be reduced in the ratio of the square of 20 to the square of 16. Hence, calling the energy of motion at the higher velocity E, and at the lower velocity E', we have—

$$\frac{E'}{E} = \left(\frac{16}{20}\right)^2 = \left(\frac{4}{5}\right)^2 = \frac{16}{25} = \cdot 64\,;$$

and,

$$E' = E \times \cdot 64.$$

It follows that $E - E'$, or the energy of motion lost, is equal to

$$E - E \times \cdot 64, \text{ or } E \times \cdot 36.$$

Again, if we compare the total energy E, of the mass on entering the atmosphere, with the energy of an equal mass moving with a velocity of 1,600 feet a second, say e, we have—

$$\frac{E}{e} = \left(\frac{20 \times 1,760 \times 3}{1,600}\right)^2 = \left(\frac{1,056}{16}\right)^2 = (66)^2 = 4,356,$$

and

$$E = e \times 4,356.$$

[1] See page 220.

But the energy of motion lost by the supposed meteoric body, in passing through the atmosphere, is $E \times \cdot 36$; it is therefore equal to

$$e \times 4,356 \times \cdot 36 = e \times 1,568.$$

Now the whole of the energy of motion thus lost is converted into heat; and therefore the heat developed by the meteoric body, in passing through the atmosphere, is 1,568 times as great as the heat that would be developed by the same mass, if it struck against an iron target when moving with a velocity of 1,600 feet a second.

Note III.

Books of Reference.

The following references will probably be found useful to those who may wish to extend their reading on the subject of Solar Energy beyond the limits of a popular lecture:—Sir William Thomson, On the Mechanical Energies of the Solar System, Trans. Roy. Soc. Edin., 1854, and Philosophical Magazine, 1854, second half-year; idem, On the Age of the Sun's Heat, Macmillan's Magazine, March, 1862; idem, Two Papers on the Sun's Heat, in Good Words, March and April, 1887; idem, On the Sources of Energy available to Man for the Production of Mechanical Effect, British Association Report, York, 1881, p. 513; Thomson and Tait, Natural Philosophy, vol. i., part ii., Appendix E, p. 485; Helmholtz, Ueber die Wechselwirkung der Naturkräfte, and Ueber die Entstehung des Planetensystems: these two magnificent lectures, which, I would venture to say, are amongst the very finest existing specimens of popular scientific discourses, will be found in a collection entitled Populäre wissenschaftliche Vorträge, published by Vieweg und Sohn, Braunschweig, 1871 and 1876; the collection has been also published in an English version by Longmans; Secchi, Le Soleil, tome ii. pp. 227–435; Proctor, The Sun: Ruler, Fire, Light, and Life, of the Planetary System, chap. viii. pp. 444–465; Newcomb, Popular Astronomy, part iv. chap. iii.; Sir Robert Ball, The Story of the Heavens, chap. xxvi. pp. 492–509; Tait, Recent Advances in Physical Science, pp. 146–175; Sir C. W. Siemens, On the Conservation of Solar Energy; Professor Stokes, Burnett Lectures, Third Course.

THE ELECTRIC LIGHT.

TWO LECTURES

DELIVERED IN THE THEATRE OF THE ROYAL DUBLIN SOCIETY,

MARCH, 1888.

LECTURE I.

HOW THE ELECTRIC CURRENT IS PRODUCED.

LECTURE II.

HOW THE ELECTRIC CURRENT IS MADE TO YIELD THE ELECTRIC LIGHT.

LECTURE I.

HOW THE ELECTRIC CURRENT IS PRODUCED.

AN Electric Light installation consists essentially of two parts: one part, in which an electric current is generated; and another, in which the energy of the current is converted into light. The electric current is now almost universally produced, for the purposes of Electric Lighting, by means of a Dynamo-electric machine, or, as it is more familiarly called, a Dynamo; and the energy of the current is converted into light in some one form or other of the Electric Lamp. I propose, then, in my Lecture to-day, to give you a short account of the Dynamo, tracing the history of its development from its first origin down to its present high degree of perfection; and in my second Lecture, I will deal with the Electric Lamp, and explain, as far as I can, the process by which the electric current is made to yield us the electric light.

Faraday's Discovery.—In the month of November, 1831, Faraday read a paper before the Royal Society of London, in which he announced, for the first time, a discovery which will be memorable for ever in the annals of science. He showed that when a closed circuit, that is to say, a conductor the ends of which are connected together electrically, is

moved in the presence of a magnet, a current of electricity is developed in the circuit, during the time of its motion. It would detain us too long to repeat all the experiments by which this discovery was established, but I can give you a general idea of the nature of these experiments in a few words.

I have got here, in my left hand, a coil of copper wire, which is covered with an insulating material, so that a current of electricity, developed in the wire, may not pass across from spiral to spiral, but must travel all round each spiral before passing to the next. In my right hand I hold an ordinary bar magnet. Now what Faraday showed was simply this: that if the ends of the copper wire are connected together, forming what is called a closed circuit, a current of electricity will be developed in the coil, when it is moved in the presence of the magnet.

To demonstrate the presence of this electric current, I have placed on the table a very delicate galvanometer, made by M. Bourbouze, of Paris. I need not tell you that a galvanometer is an instrument whose function it is to reveal the presence of a current of electricity, and at the same time to indicate the direction in which the current flows. This particular instrument before you is provided with a long index, which is visible I hope to all present, and which now points to zero on the scale: but when a current of electricity flows through the apparatus, the index will be deflected from its position of rest, and will swing to the right or to the left, according to the direction in which the current is flowing.

My assistant will now connect the ends of the coil with the binding screws of the galvanometer, by means of light

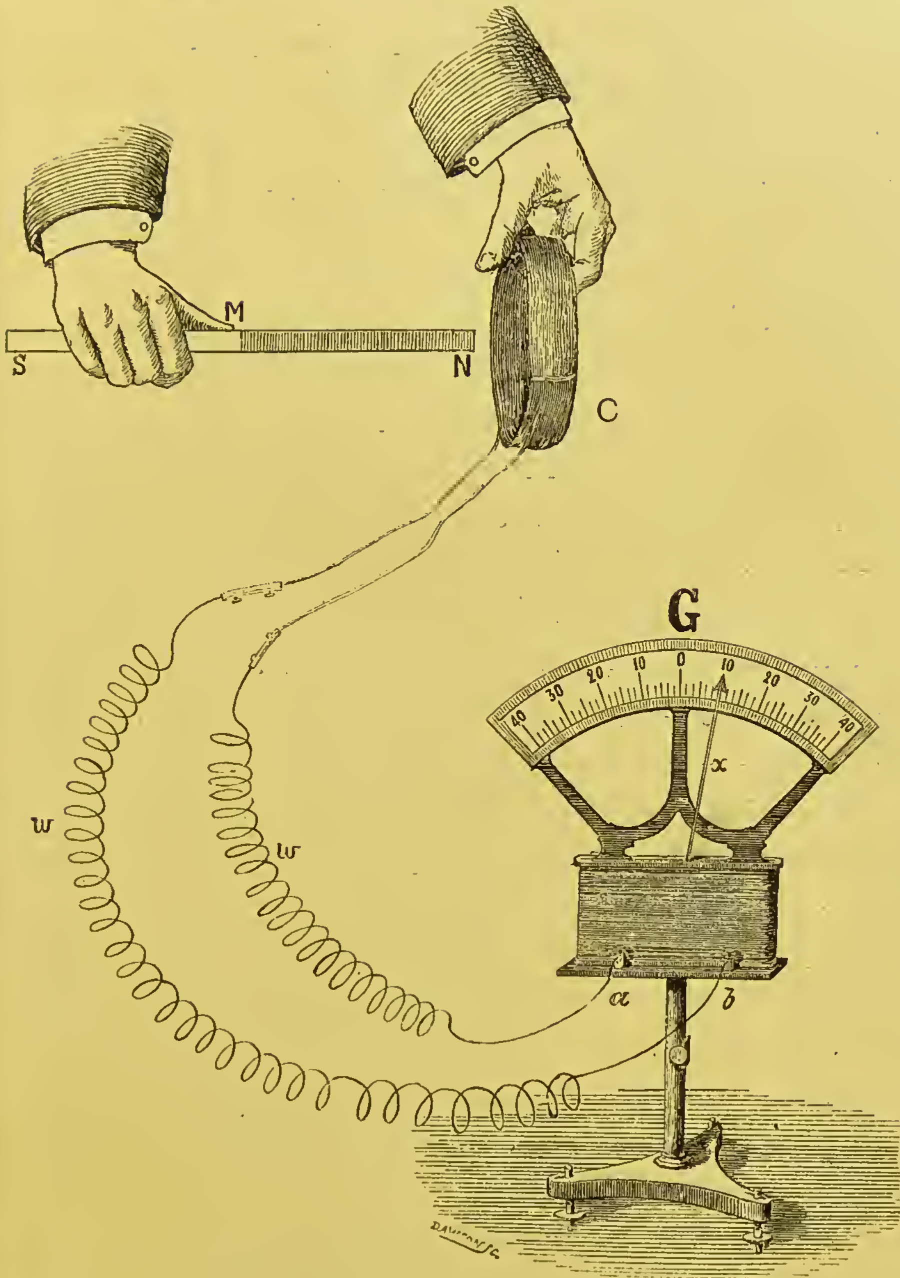

Fig. 33.

Current of Electricity produced by the Motion of a Coil of Wire in Presence of a Magnet.

M Bar Magnet.
C Coil of Copper Wire.
w w Wires conveying the Current.
G Sensitive Galvanometer.
a b Binding Screws of Galvanometer.
x Index of Galvanometer.

flexible wires. In so doing, he practically makes a closed circuit, of which the coil of copper wire is one part and the galvanometer another: and now, if an electric current is developed in the coil, it must flow through the galvanometer, and its presence will be revealed by the deflection of the index.

With this apparatus I can reproduce in substance the experiments of Faraday, so as to make the results apparent to every one present. I move the coil towards the north pole of the magnet, and the index of the galvanometer swings to the right, showing that a current has passed. But observe, the index, after swinging back and forward a few times, comes to rest again, at zero; from which we may infer that, when the coil and the magnet are both at rest, no matter how close they may be, no current is produced. Next, I move the coil away from the north pole, and again the index is deflected; but this time it swings to the left, showing that the new current developed is opposite, in direction, to the former.

I repeat these experiments with a south pole. When I move the coil towards the south pole, the index swings to the left; when I move it away, the index swings to the right. Thus we learn that the current produced by the action of a south pole is, in each case, opposite in direction to that produced by a north pole.

Pursuing these experiments, Faraday further showed that the current is greatly intensified, if the copper wire is wound round a bar of soft iron. He also showed that the current developed is stronger, in proportion as the magnet employed is more powerful, and in proportion as the motion is more

swift. And lastly, he showed that the current is equally produced, in all cases, whether the magnet is at rest and the coil is moved, as was the case in our experiments, or the coil is at rest and the magnet moved. These are the main facts which Faraday established by experiments carried out in the Royal Institution of London, just fifty-seven years ago; and upon the basis of these facts, it is simply true to say, have been built up all the Dynamo-Electric machines that are now at work in the world.

Faraday was himself fully conscious of the importance of the discovery he had made; and he believed it to be capable of many useful applications. But these applications he left to others to seek out; and having handed over his discovery to the world, with all its potency of future development, as an inheritance for ever, he turned his attention to new fields of research, in the hope of discovering new truths, and enlarging still more the bounds of human knowledge.

First Machines founded on Faraday's Discovery.—The first practical application of Faraday's discovery to the construction of a machine for generating an electric current was made in 1832, by Pixii, a manufacturer of philosophical instruments in Paris. You will easily understand the construction of his machine from the diagram before you. Two bobbins of wire, B B, each having within it a core of soft iron, are mounted in a fixed position on the solid frame A. Immediately below the bobbins is a horse-shoe magnet M, so adjusted that it can be made to rotate rapidly by means of the wheel and pinion P. As the magnet rotates, its poles pass alternately close before the face of each bobbin; currents of electricity are thus generated in

the bobbins, and these currents are carried, by the wires *a a*, to the spring contacts *b b*, from which they pass to the com-

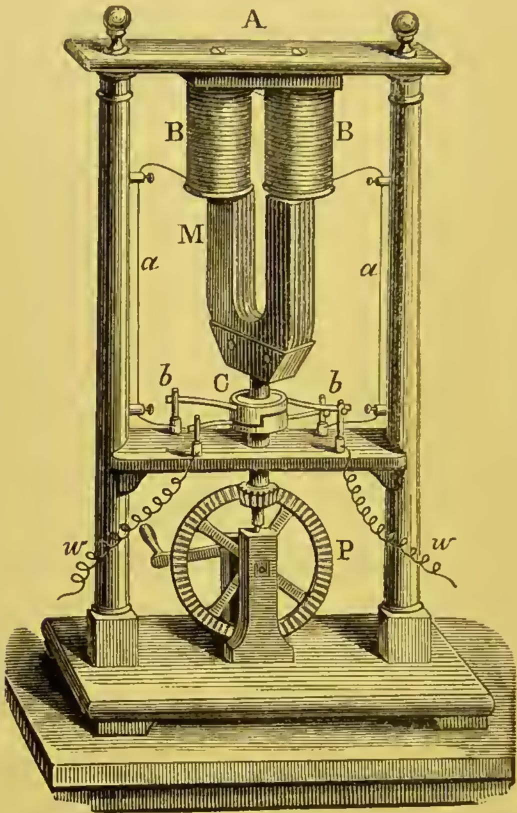

FIG. 34.

PIXII'S MACHINE, 1832.

B B Bobbins of Wire.
M Horse-shoe Magnet.
P Wheel and Pinion to drive round the Magnet.

a a Wires to carry the Currents from the Bobbins to the contact pieces *b b*.
C Commutator to collect the Currents and transmit them to the Wires *w w*.

mutator C. From the commutator the currents are transmitted to the wires *ww*, by which they may be conveyed to any external circuit, for practical use.

It was soon found, however, that it was more convenient to make the bobbins of wire revolve before the poles of the

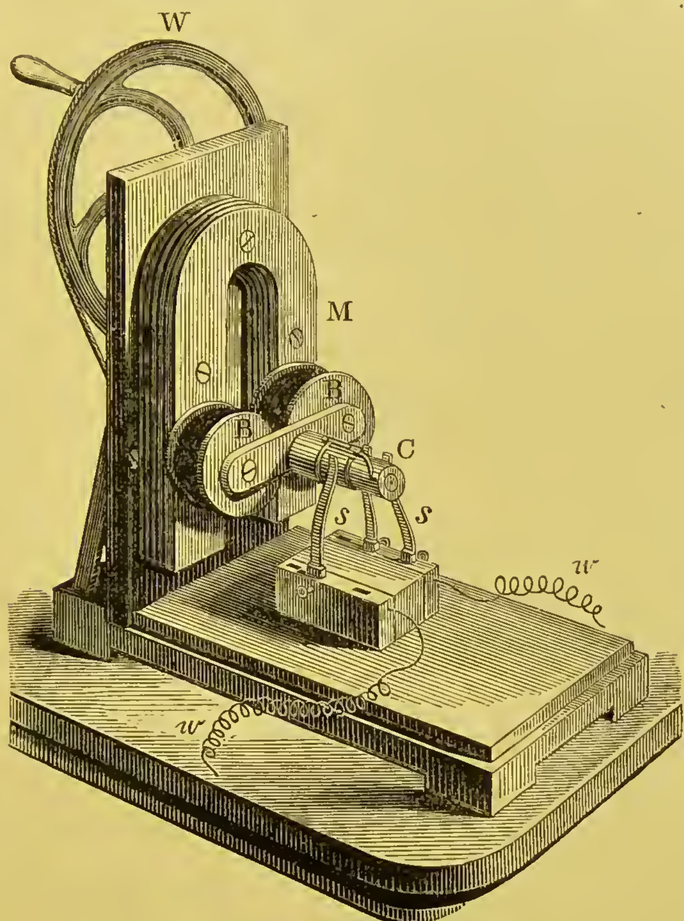

Fig. 35.

Clarke's Machine, 1836.

M Horse-shoe Magnet.
B B Bobbins of Wire.
W Wheel to drive the Bobbins.
C Commutator.
s s Springs to convey the Currents from the Commutator to the external Circuit, through the Wires *w w*.

magnet, than to make the poles of the magnet revolve before the bobbins. This modification was first introduced by Saxton, in the year 1833, and was afterwards adopted by

Clarke, whose machine, first brought out in 1836, has survived, in one form or another, down to the present day. The diagram on the wall represents one of the earliest forms of Clarke's machine: M is the horse-shoe magnet, B B are the bobbins of wire, and W is the wheel by means of which the bobbins are made to rotate before the poles of the magnet. The currents of electricity developed in the bobbins pass to the commutator C, which is fixed on the axis of rotation; and from the commutator they are conveyed by the springs *s s*, which press against the commutator as it revolves, to the wires *w w*, by which they pass into the external circuit.

Clarke's machine has been found very convenient for medical purposes, and it is in general use, even at the present day, amongst medical men, in a great variety of forms. The specimen here on the table, made by Gaiffe of Paris, is one of the most recent: it is firmly fixed in a rectangular box to make it more portable, and it is provided with a variety of appliances by which the currents developed may be conveyed to various parts of the human body.

I should tell you that, in all these machines, the electric currents developed in the coils of wire flow in one direction during one half of each revolution, and in the opposite direction during the other half revolution. You will remember that, in repeating Faraday's experiments, a little time ago, I showed you that when a coil approached a magnetic pole, the current flowed in one direction, and when the coil receded from the pole, the current flowed in the opposite direction. I showed you also that the currents developed by motion to or from a north pole are always

opposite to the currents developed by motion to or from a south pole. It is a consequence of these laws that, in the machines before us, the currents generated in each half revolution of the bobbins are in opposite directions. Hence, if we connect the ends of the wire coming from the bobbins directly with an external circuit, the currents will flow alternately in opposite directions in the external circuit. But an ingenious contrivance, called a commutator, has been devised, by means of which the currents, though flowing alternately in opposite directions in the bobbins, are all sent into the external circuit in the same direction.

I need not trouble you with the mechanical details of the commutator. Enough it is to know that we have two types of machine. In one type, where the commutator is not employed, the currents in the external circuit flow alternately in opposite directions; in the other, where the commutator is introduced, the currents in the external circuit flow all in the same direction. The one type is called the alternate current machine; the other is called the continuous current machine. Both types are in general use: and both, I may say by anticipation, are at the present moment employed for producing the Electric Light.

Siemens' Armature.—In the progress of scientific discovery there are periods of activity and periods of repose. The production of Clarke's machine, in 1836, was followed by a long period of repose; for no further improvement was made from that date until 1857, when Dr. Werner Siemens, of Berlin, introduced a new method of winding the bobbin of wire, or armature, as it is called. You will have observed that, in the machines I have already described, only

one face of each bobbin comes close to the poles of the magnet; the other face is always turned away, and therefore the influence of the magnet upon it must be comparatively feeble. Siemens conceived the idea of so constructing his bobbin that each face of the coil might come close to the magnet poles, and the inductive effect of the magnet be thereby greatly increased.

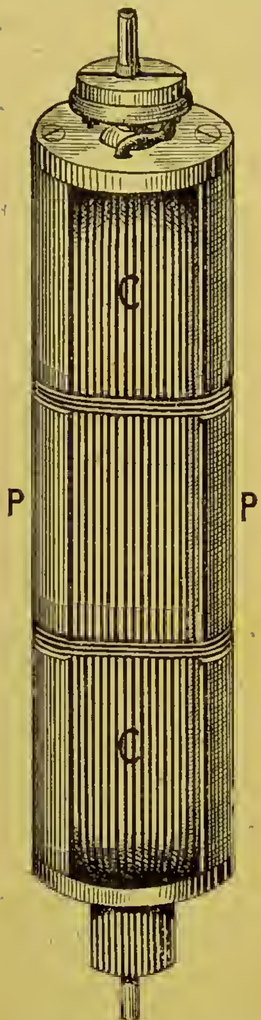

FIG. 36.
SIEMENS' ARMATURE, 1857.

Here is one of his bobbins in the form in which they were first brought out; and here is the machine in which it works. The bobbin is prepared by taking a cylindrical bar of soft iron, and cutting a deep wide groove on both sides all along its length. The insulated copper wire is then wound, in this groove, like thread upon a shuttle. In the machine, a number of horse-shoe magnets are mounted on a stand, with all the north poles on one side, and all the south poles on the other. These poles are so shaped as to allow the cylindrical armature to fit between them, with just room enough to rotate freely.[1] When the armature is put in rotation each face of the coil comes alternately, first opposite one row of poles, and then opposite the other, and inductive action takes place under the most favourable conditions.

[1] For a figure of Siemens' machine, see p. 264.

First Machines for Production of the Electric Light.— Soon after the introduction of Siemens' armature, practical men began to realize that the power of these machines might be increased almost indefinitely. It was only necessary, following out the principles laid down by Faraday, to get

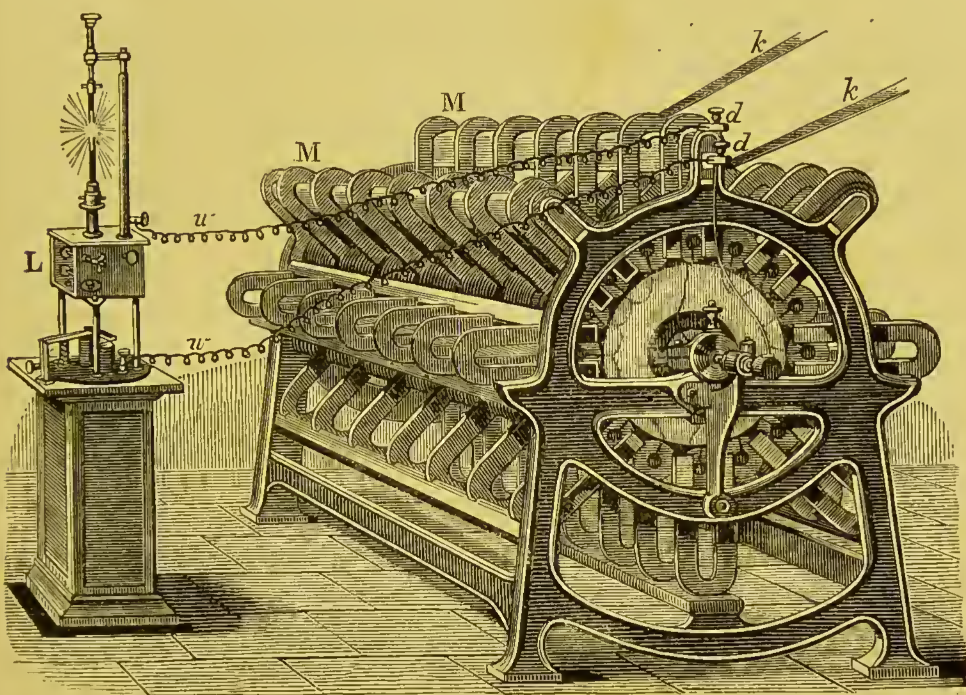

FIG. 37.

MACHINE OF THE ALLIANCE COMPANY, 1863.

M M Horse-shoe Permanent Magnets.	w w Wires for conveying the Current from Machine to Lamp L.
k k Belt for driving Armature.	

larger magnets and a greater number of them, to coil more wire on the armature, and to drive it at a greater speed, and an electric current might be generated far surpassing any that had ever been obtained from batteries. It was

suggested, too, that such currents might be used with great advantage to produce the electric light for the illumination of Lighthouses.

This idea was taken up about the same time in England and in France, and was soon carried to a successful issue. A very powerful machine, constructed by the Alliance Company, in France, and driven by a steam-engine, was established at the Lighthouse of Cape La Hève, near Havre, about the year 1863, and used from that time forward for the production of the Electric Light. The construction of the Alliance machine may be easily understood from the diagram before you. You see here eight rows of magnets M M, mounted on a massive frame, with seven magnets in each row, or fifty-six magnets in all. Between the poles of these magnets a large Siemens' armature is driven round by the belt *kk*; the currents are collected at the binding screws, *dd*, and are carried by the wires *ww* to the lamp L.

A machine quite similar to this was constructed, in England, by Holmes, who had previously been in the service of the Alliance Company, and was mounted on the sixth of June, 1862, at the South Foreland Lighthouse, where it continued to be worked very successfully for many years. This machine, at the South Foreland, is particularly interesting, because it was set up under the direction of Faraday himself, who, at the time, was scientific adviser to the Elder Brethren of Trinity House, and who thus had the satisfaction of seeing, after the lapse of thirty years from the date of his great discovery, this offspring of his own genius already arrived at maturity, and entering on a career of usefulness which is likely to last as long as the world itself.

First Machine with Electro-magnet.—But these machines, though successful for their time, were bulky and cumbrous; and hardly had they been seen in action, when the idea was suggested that a great saving might be effected, in size and weight, by the employment of electro-magnets, instead of permanent steel magnets. An electro-magnet, as I dare say you know, consists of a bar, or plate, of very soft iron, round which is coiled an insulated copper wire. Here is one, bent into a horse-shoe shape, and suspended from this tripod stand. It shows no sensible signs of magnetic power, when I present to it a tray of iron nails. But the moment I turn on an electric current, and make it flow round the coil of copper wire, you see how the nails are suddenly attracted, and held suspended in the air, the magnetic power passing through the mass, so that they stand out in a cluster round the poles of the magnet. Again, when I shut off the current, the magnetism of the soft iron bar is lost as suddenly as it was acquired, and the nails fall down, in a heap, to the ground.

What you have chiefly to observe in this experiment is first, that an electro-magnet is far more powerful than a permanent steel magnet, of equal weight; and secondly, that it can acquire its magnetic power in a moment, and lose it in a moment. But I would ask you also to notice an incidental circumstance of the experiment, which though apparently trivial, has a singularly interesting application, as you will see by-and-by, in the Dynamo-Electric machine.

Observe that, although the great mass of nails has fallen down from the poles of the electro-magnet, there are one or two of the smaller nails still feebly clinging to it. To satisfy

you that this is not a mere accident, I repeat the experiment again and again: each time, when the current is shut off, two or three small nails remain attached to the poles of the magnet. From this we may infer that, although the iron bar loses its magnetism, when the current ceases to pass, it does not lose it altogether; some faint traces still remain. This is called residual magnetism: and I ask you now to take a note of it, because you will see, a little later on, what an important part this residual magnetism will be called upon to play, in the development of our machine.

The idea of using an electro-magnet in the construction of a Dynamo was first carried out by Wilde of Manchester, in 1867. From the diagram before us, it will be seen at once that Wilde's machine consisted of two parts. The upper part is simply a machine of Siemens, such as I have just described to you. Here is a row of permanent horse-shoe magnets M, with two oblong masses of soft iron as pole pieces. Between these pole pieces a Siemens' armature, one end of which is seen at *r*, is made to rotate by the belt *b b*.

The electric current generated in the armature, instead of being carried off to the external circuit, is conveyed from the binding screws *p q*, round the coils of a large electro-magnet D D, imparting to it a magnetic power far surpassing that of the permanent magnets above. Between the pole pieces of this electro-magnet, a second Siemens' armature, very much larger than the first, one end of which appears at F, is driven round by the belt *k k*, which is worked by a steam engine not shown in the sketch; and an electric current of great power is produced, which passes

to the external circuit by the wires *w w*. This machine was first exhibited before the Royal Society of London in March,

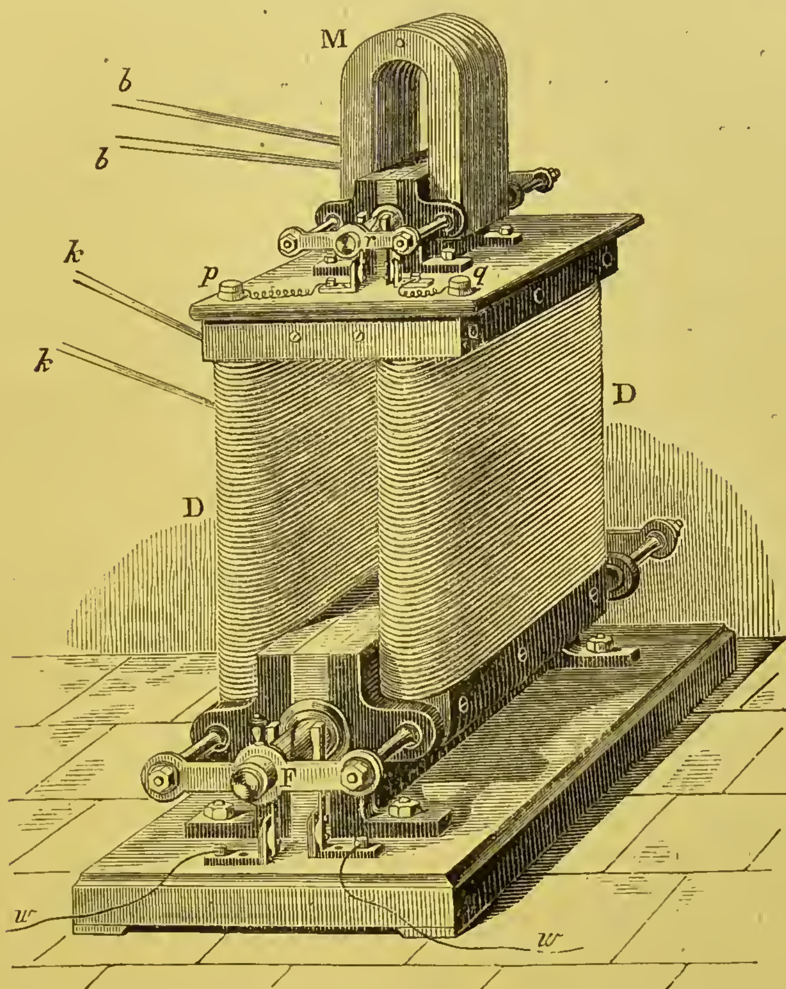

Fig. 38.

Wilde's Machine, 1867.

M	Row of Permanent Magnets.
b b	Belt to drive Armature of Small Machine.
D D	Large Electro-magnet.
k k	Belt to drive Armature of Large Machine.
w w	Wires to carry Current to external Circuit.

1867, and afterwards at the Paris Exhibition in the summer of the same year, where it attracted very general attention.

A new Principle discovered.—But Wilde's machine was hardly finished when it was superseded by a new discovery, made about the same time by Dr. Werner Siemens, of Berlin, and Professor Wheatstone, of London. The practical result of this discovery was to show that the upper part of Wilde's machine was unnecessary; inasmuch as the current required to excite the electro-magnet can be obtained from the action of the electro-magnet itself. At first sight, this statement looks like a paradox: we are to produce a current by means of an electro-magnet, and we are to make the electro-magnet by means of the current so produced. But the explanation is to be found in the phenomenon of residual magnetism, to which I called your attention a little time ago.

An electro-magnet, once excited, retains, for a considerable time, some faint traces of magnetism. Hence, if we suppose the upper part of Wilde's machine to be removed, and the armature in the lower part to be put in rotation, it would rotate, in fact, between the poles of a feeble electro-magnet, and accordingly a feeble current of electricity would be developed in the coils of the armature. Now this current may be conveyed round the coils of the electro-magnet, so as to increase its magnetic power, and thereby to increase the strength of the current developed in the armature. The same arrangement will convey this stronger current round the electro-magnet, thereby increasing still more its magnetic power, and increasing, at the same time, the strength of the current developed. And so the process may be continued, the power of the magnet and the strength of the current being rapidly exalted, until a certain maximum is attained

at which the current is able to maintain the magnet at a high degree of magnetic intensity, and to do work in the external circuit as well.

This principle, which was destined to bring about a revolution in the construction of Dynamo-Electric machines, was brought under the notice of the Academy of Science of Berlin by Dr. Werner Siemens, in the month of January, 1867, and in the following month of February it was brought before the Royal Society of London, by Professor Wheatstone, who had discovered it independently for himself. It soon received practical application, in a machine constructed by Mr. Ladd of London, which was exhibited at the Paris Exhibition in the summer of the same year.

But Ladd's machine, though it attracted a great deal of notice on account of the novel principle it embodied, never came much into practical use. It was followed, however, after a brief interval, by two machines, founded on the same principle, which may be said to mark an epoch in the history of our subject; I mean Gramme's machine, which was brought out in 1871, and Siemens' machine, which appeared in 1873.

It is worth while to dwell for a few moments on the construction of these two machines; for practically they furnish the types on which almost all the various forms of Dynamo machines have been since constructed. They differ from one another, chiefly in the way in which the insulated copper wire is wound on the armature, or rotating bobbin; Gramme having invented a new form of armature, and a new mode of winding the wire, while Siemens adopted a modification of the armature previously invented by himself, the construction of which I have already explained to you.

The Gramme Machine.—I think I can best give you a clear idea of the principle of the Gramme machine if I show you, in the first instance, not the machine itself, but an ideal

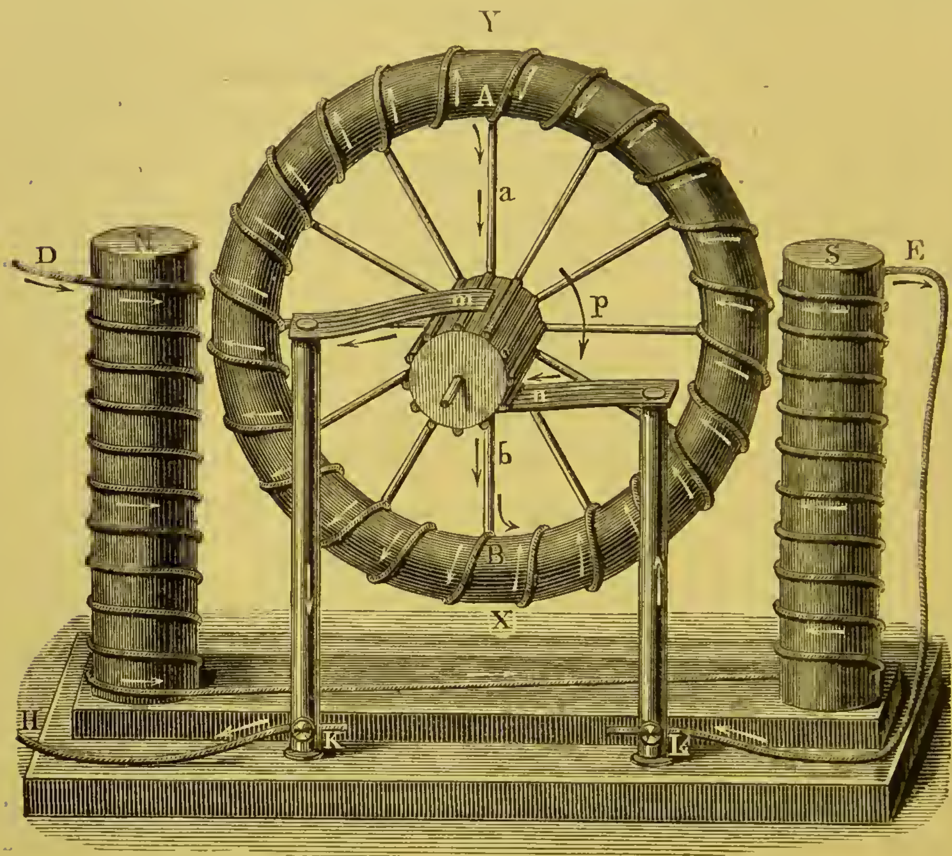

FIG. 39.

IDEAL SKELETON OF GRAMME'S MACHINE.

A B Ring of Soft Iron.
N S Poles of Electro-magnet.
m n Copper Springs to collect the Current.

The Arrow *p* shows the Direction of Rotation.
The other Arrows show the Direction of the Currents.

skeleton, which exhibits all its essential parts, in their simplest form. In the diagram before you A B is a ring of soft iron, round which is coiled an insulated copper wire, with its ends

connected together so as to form a continuous circuit. This ring can be made to rotate on its axis between the poles N S of an electro-magnet. How the magnetism of the electro-magnet is established and maintained I will explain by-and-by: for the present I simply assume that N and S are two magnetic poles, north and south respectively.

Now let the ring revolve in the direction of the arrow *p*. It may be shown, according to the principles established by Faraday, that as each spiral of the coil moves onward from X towards N a current of electricity is generated, which flows in the direction marked by the arrows: and again, as each spiral moves away from N towards Y, a current of electricity is also developed, and in the same direction. Thus while the ring is revolving, as supposed, a force is developed which tends to make an electric current flow in that half of the ring which, for the time being, is on your left hand, from X upwards to Y. Similarly it may be shown that a force is developed in that half of the ring which, for the time being, is on your right hand, and this current too is from X upwards towards Y.

It is usual to conceive the action of these two forces as producing, on both sides of the ring, a gradual rise of what is called Potential between the spiral which, at any moment, is passing the point X, and the spiral which, at the same moment, is passing the point Y. Thus a Difference of Potential is maintained between the spiral which, for the time being, is at X, and the spiral which, for the time being, is at Y; the former being always at the lowest Potential, and the latter at the highest, of the whole coil. Now a Difference of Potential as regards electricity is like a

difference of level as regards water. Water always tends to flow from a higher level to a lower level, and, when it flows, it is able to do work: so, too, electricity always tends to flow from a point of higher Potential to a point of lower Potential, and as it flows it is able to do work. Hence if a conductor of electricity be introduced between the spiral which for the time being is passing Y, and the spiral which for the time being is passing X, a current of electricity will flow through such a conductor, and may be used to do work as it flows.

But how are we to introduce such a conductor, seeing that the spirals are all in motion, and that they are covered with an insulating material? The answer to this question leads us to one of the most ingenious devices of the Gramme machine. You will observe that every second spiral of the coil communicates with the axis of the ring, by means of a radius which is made of a good conducting material, and which connects the wire with a narrow copper plate, set edgeways in the circumference of the axis. Thus each of these little copper plates is, at every moment, in the same electrical condition as the corresponding spiral of the ring.

Now look at the two brass pillars in front of the ring. Each has attached to it a light copper spring. The one above, marked *m*, presses gently on the copper plate which is connected, through the radius *a*, with the spiral at the moment passing the point Y; the one below, marked *n*, is similarly pressing on the copper plate which is connected, through the radius *b*, with the spiral at the moment passing the point X. Hence the copper spring *m*, and the binding screw K connected with it, are always at the higher potential belonging to the spiral at Y; and similarly the spring *n* and

the binding screw L are always at the lower potential belonging to the spiral at X. If, then, we connect K and L by means of a wire, a current will flow through the wire, and we can use it to produce the Electric Light, or to do any other kind of work.

Let us now come back to the Electro-magnet. I have hitherto assumed that it has magnetic power, all through the process I have described: it remains for me to show you how that magnetic power is imparted to it. At the outset, as I have already explained, the electro-magnet has some residual magnetism, which though feeble produces its due effect, and develops a feeble electric current in the rotating ring. This current is carried off to the external circuit by the wire H, and coming back at D, is carried round the electro-magnet, so as to make N a stronger north pole, and S a stronger south pole, than they were before. The stronger magnetism develops a stronger current, and this stronger current, carried round the wire coils, increases still more the strength of the magnet; and so the strength of each is alternately increased, until, in less time than it takes to tell it, the maximum power of the machine is reached.

Details of Construction.—This is the general principle of the Gramme machine, according to its simplest conception. In the machine itself, as will now be easily understood, the essential elements are: first, the electro-magnet; secondly, the ring armature; thirdly, the narrow copper plates set edgeways in the axis of the ring, which taken collectively are called the commutator; and fourthly, the copper springs, which convey the current from the commutator to the binding screws.

The electro-magnet is made of two massive bars of very soft iron, with pole pieces attached, which are so arched as partly to enclose the armature between them. The wire used for winding the electro-magnet varies indefinitely in length and thickness, according to the purpose for which the machine is intended. In the armature, the soft iron core is not usually made of massive iron, as represented in the ideal sketch, but of thin iron wire, which is coiled into the form of a solid ring. This iron ring is then wound over with insulated copper wire, which is divided into a great number of sections, one end of each section being connected with one plate of the commutator, and the other end with the next plate. By this arrangement, as each section passes through the position of highest potential, that is, the position Y of the ideal sketch, the corresponding plate of the commutator will be at the highest potential; and in like manner, as each section passes through the position of lowest potential, the position X of the ideal sketch, the corresponding plate of the commutator will be at the lowest potential.

The construction of the armature will be more fully understood by the aid of the diagram before you, which represents a Gramme ring cut across at one side, and partly opened out. At A and B are seen the cross sections of the iron wire forming the ring; *s s* and *c c* are the divisions, or sections as they are called, of the insulated copper wire, which is wound round the ring; R R represent the plates of the commutator, which are separated from one another by thin layers of some insulating material, shown at H. It will be observed that the sections of the coil are shown, in the lower part of the figure, separated out from one another,

the ends of the wire in each section being left exposed; but in the upper part, the sections are shown as they actually exist in a working ring, closely pressed up together, and connected by the ends of the wire with the plates of the commutator.

The copper springs, represented by *m* and *n* in our ideal sketch, are now called the brushes, and consist in the smaller machines of a bundle of wires; but in larger machines

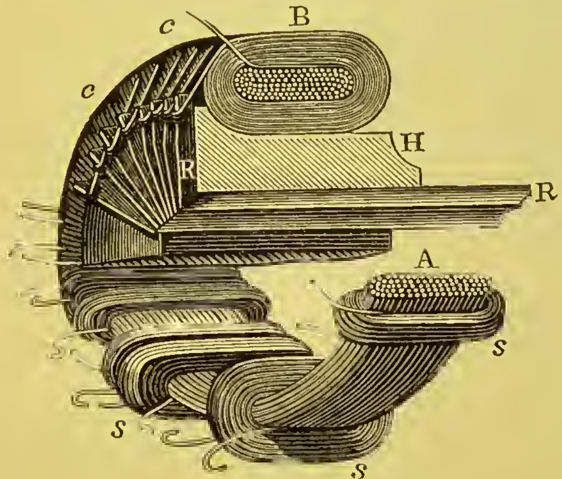

Fig. 40.

Construction of the Ring Armature.

A B	Cross section of the Ring showing the Coil, and the Iron Core within.	*s s*, *c c*,	Sections of the Coil.
		R R	Plates of the Commutator.
		H	Layer of Insulating Material.

they are generally made of thin copper plates. They are so adjusted that one is always pressing lightly on that plate of the commutator which, for the moment, is in the position of highest potential, and the other on that plate which, for the moment, is in the position of lowest potential. Thus the electric current generated in the armature always tends to flow from one brush to the other, through any conductor that

may offer it a passage; and the conductor is so arranged as to carry the current through the coils of the electro-magnet, where it maintains the magnetic power of the soft iron, and through the external circuit where it does work.

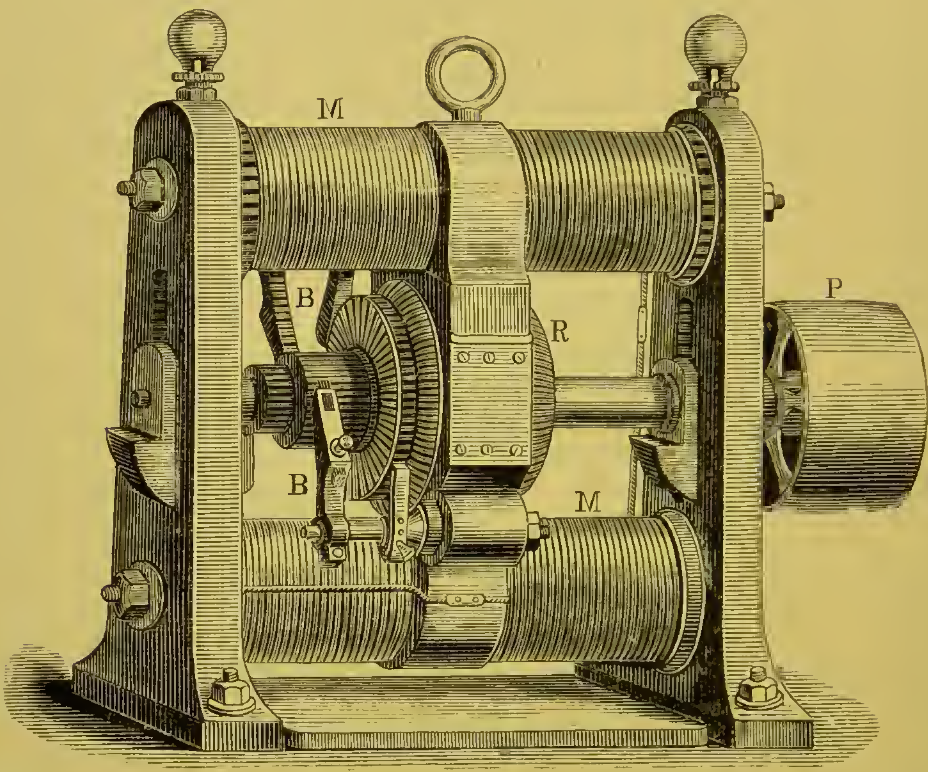

FIG. 41.

GRAMME'S MACHINE, WORKSHOP TYPE, 1873.

M M Electro-magnets.
R Ring Armature.
B B Brushes to collect Current.
P Pulley to drive Armature.

In the machine on the table, you will now easily recognise all the elements I have just described, built up into a compact and solid structure. It is an early form, though not the very earliest, of Gramme's machine, and has done good

service in its time: it is called the Type d'Atelier, or Workshop Type. These two massive horizontal bars, one above and one below, are the electro-magnets. The coils of the magnets are so wound that the poles are in the centre; and you can see the great pole pieces, one above and one below, arched as I have described them, and encircling a large part of the ring armature, which has just room to revolve between them. The armature itself is partly concealed from view; but enough is exposed to make it plainly visible, as I turn it slowly round between the poles of the magnet. On the axis of the armature you can see, too, the narrow edges of the commutator plates, which are here sixty in number. And lastly, here are the brushes, pressing lightly on opposite sides of the commutator, which collect the current and make it available for use in the external circuit.

This machine of Gramme's is curiously associated with the memory of the first Napoleon. On the tenth of November, 1801, or, as it was then called, the nineteenth Brumaire of the year X, a paper was read before the Institute of France, by the celebrated Volta. The subject of the paper was the well-known battery which he had just invented, and which has since been called, after him, the Voltaic Battery. The First Consul was present at the meeting; and being greatly struck by the prospects which the paper seemed to unfold, he offered a prize of 60,000 francs, to be open to the scientific men of all countries, and to be called the Volta Prize, for the best practical applications of the power of electricity.

This Prize was renewed by Napoleon the Third, by whom it was awarded three times, the amount, however,

being reduced to 50,000 francs. It was again awarded under the Republic, in 1871, almost immediately after the close of the Franco-Prussian war. The last competition for it was opened in July, 1882, and closed in July, 1887 ; and on this occasion the Prize was awarded to Zénobie Théophile Gramme, for the invention of his Dynamo-Electric machines.

It is interesting to know that, even so late as 1862, M. Gramme was a working carpenter in the employment of Rumkorff, a well-known maker of philosophical apparatus in Paris. He had no scientific training ; but having been engaged to finish the woodwork of some electrical machines, he was fascinated by the mysterious power with which he found himself brought into contact, and by the sheer force of native genius and indomitable perseverance, he achieved the great triumph of constructing a machine which marks a new epoch in the history of the industrial arts.[1]

I will not trouble you any further with details of construction. The machine invented by Siemens of Berlin differs from Gramme's machine only in the way of winding the armature: and the great majority of machines now made follow, in the main, one or other of these two types. Though the modifications and improvements introduced, during the last fifteen years, are countless in their variety, yet the same essential elements are common to all machines. There is the armature, or rotating bobbin of wire ; there are the massive electro-magnets ; there is the commutator, with its numerous copper plates, set edgeways on the axis of the revolving armature ; and there are the brushes, which collect the

[1] See The Electrician, July 27, 1888, p. 364 ; and August 24, 1888, pp. 496, 497.

current from the armature, and send it round the coils of the electro-magnet and into the external circuit.

The Dynamo does not Create Energy.—Before closing this branch of my subject, I should wish to remind you that the Dynamo does not create the electrical energy it sends forth. It is a law of nature that the sum total of the energy, in the material universe, remains always the same: it suffers no loss, and it receives no accession. It is given to man to use it as he pleases; but, in using it, he can only change it from one form to another: he has no power to increase the store, or to annihilate any part of it. We cannot, therefore, get a stream of electrical energy to flow from our Dynamo unless we expend some other kind of energy in producing it; and the energy so expended must be always proportional to the electrical energy we want to produce.

Let me try to bring this important truth home to you by an experiment. Here is a good-sized specimen of one of the earliest forms of Siemens' machine. It is a machine with permanent magnets, such as I have already described, and is made to be worked by the hand, the armature being driven round by means of this wheel. The binding screws of the machine are connected by light flexible wires with the commutator on the table; and, by turning the handle of the commutator, I can complete the circuit through this platinum spiral, or I can interrupt the circuit, just as I please. When the circuit is interrupted, no current is produced, no matter how fast the bobbin of wire may be forced to rotate; but when the circuit is complete, a current is at once developed in the rotating bobbin, and flows through the platinum spiral.

Now what I want you to observe is this. When the circuit is interrupted, and no current is produced, the bobbin of wire is driven round with ease: it is only necessary to impart a certain velocity of rotation to a comparatively small mass of matter, and to overcome the friction of the machine. But when the circuit is closed, and the bobbin can no longer

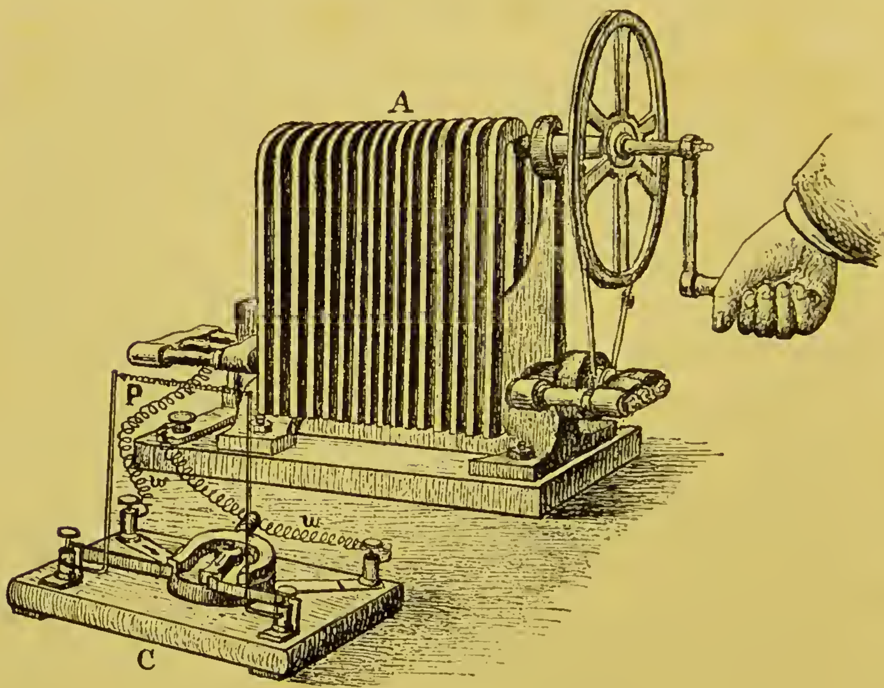

Fig. 42.

Expenditure of Energy in Production of Electric Current.

A Early Form of Siemens' Machine.
ww Wires conveying Electric Current.
C Commutator for closing and breaking the Circuit.
P Platinum Spiral.

continue to rotate without producing an electric current, then a far greater amount of labour must be expended to drive it. This is the fact you have to observe: and with this fact before your eyes you will readily admit the inference, that

the additional work done, when the circuit is closed, is the mechanical equivalent of the electrical energy produced.

My assistant will now turn the wheel. The circuit is at present interrupted, and you see with what ease he makes the bobbin fly round at a rapid rate. I turn the handle of the commutator: the circuit is now closed. It is like putting on a break: every one can see how much harder my assistant has to work to keep the bobbin going; and, at the same time, the platinum spiral begins to glow with a bright red light, which shows that a current is passing. I reverse the motion of the handle: my assistant is, at once, relieved; and the little platinum lamp goes out, showing that the current has ceased to flow. I close the circuit once more: once more he is obliged to use all his efforts to force the bobbin round; and once more the glowing of the platinum lamp tells us that the additional work expended has resulted in the production of an electric current.

Electrical Energy produced in Dynamo is due to Mechanical Energy expended.—We learn then that the electrical energy developed in a Dynamo is the product of the mechanical energy expended in driving it. It follows that the electrical energy developed can never exceed the mechanical energy expended. Practically it is always less; because a certain portion of the mechanical energy goes to overcome the friction of the machine, and is therefore converted directly into heat, and not into electrical energy. A portion, too, of the electrical energy developed is expended within the machine itself, and is not available for practical use. But notwithstanding the loss of energy, arising from these two causes, so great is the perfection to which the Dynamo has now been

brought, that from eighty to ninety per cent of the work done in driving the machine is sent forth in the form of

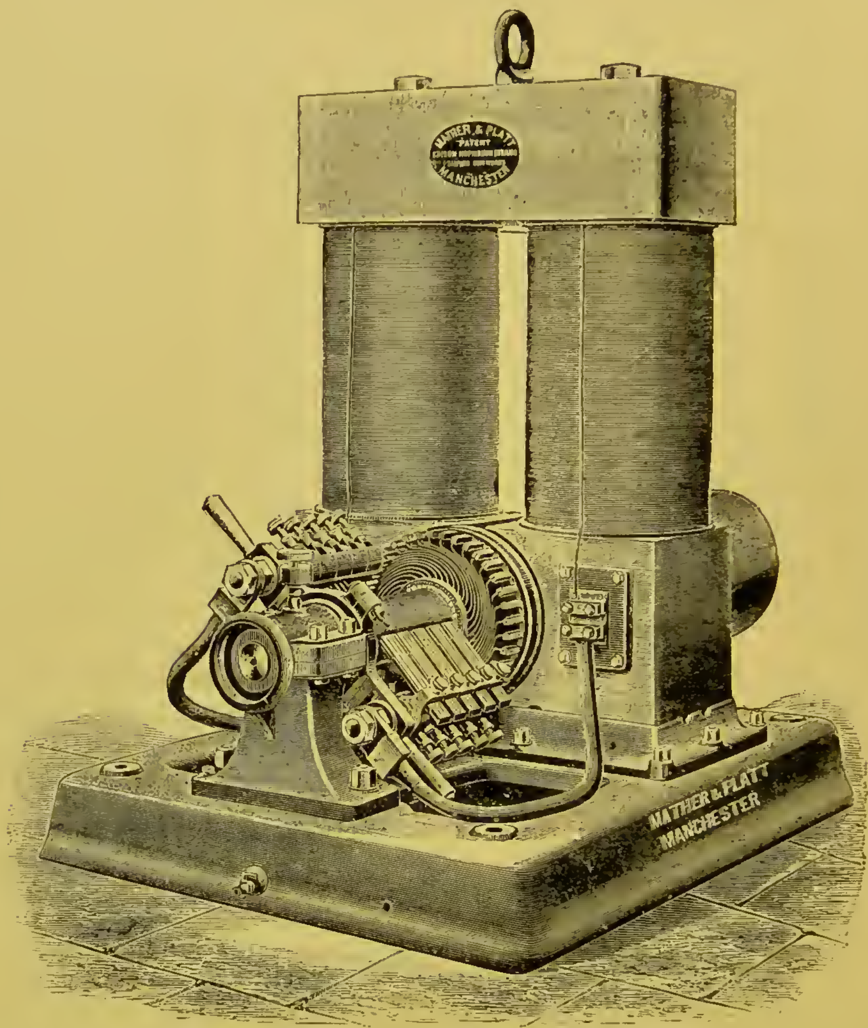

FIG. 43.

THE EDISON-HOPKINSON DYNAMO.

electrical energy, and may be turned to useful account for Electric Lighting, and for other kinds of work.

The diagram before you, which represents the machine known as the Edison-Hopkinson Dynamo, made by Messrs. Mathers and Platt of Manchester, will give you a good idea of the modern Dynamo, in one of its finest forms. In this machine the electrical energy available for the external circuit is stated to be over ninety per cent of the mechanical energy applied to drive it, and is capable of maintaining more than a thousand incandescent lamps of sixteen candle-power each.

I have now brought to a close the first part of my subject. I have endeavoured to present to you, in a rapid sketch, the history of the Dynamo, from the first discovery of the fundamental principles on which it is founded, down to the present time; and I have tried to make you realize that, with all its varieties of form and detail, it is, in its essence, simply a machine for converting mechanical energy into the energy of an electric current. In my next Lecture I will try to show you how the energy of the electric current is converted into light.

LECTURE II.

HOW THE ELECTRIC CURRENT IS MADE TO YIELD THE ELECTRIC LIGHT.

WHEN an Electric Current passes through a conductor, the conductor is heated; and if the current is strong enough, and the conductor is suitably chosen, it can be raised to a very high temperature, and made to shine with a bright light. This phenomenon may be shown, in its simplest form, by means of a spiral of platinum wire, such as is mounted on this little stand before you.

Simplest Form of Electric Light.—I first turn on the current from two cells of a Storage Battery, in the next room: the platinum spiral is sensibly hot to the touch, but there is no glow of light. I add three cells more, and the spiral gets red. I increase the number to eight, and it now emits a pure white light of great brilliancy.

You will expect, perhaps, that I should explain the nature of the process by which heat is thus produced in this wire while the current is passing through it. That is a matter, however, which is not yet perfectly understood. We do not know what the electric current is, in itself; much less do we know what is the nature of the process that goes on in the wire, when, as we say, the current is passing through it; and therefore we cannot

really explain how the heat is produced. But we are not altogether ignorant on the subject: we know a little, and that little is easily told. We know that an electric current has energy; we know that it encounters resistance in the platinum spiral, that it overcomes that resistance, and that, in doing so, it expends a part of its energy; and we know that the energy so expended is converted into heat.

Let me illustrate these fundamental conceptions by a familiar example. Every schoolboy knows that if he takes a brass button, and rubs it very hard against a deal board, he can make it so hot that he can hardly bear to touch it. Now, where does this heat come from? You will probably say, "Oh, we know all about that; that's friction." Well, you are quite right: but what is friction? It is a kind of force existing between the surface of the brass button and the surface of the deal board, and tending to prevent the one sliding over the other. But in spite of that force the schoolboy makes the button slide to and fro: in doing so he expends muscular energy: the energy so expended passes away from him for ever; and in its stead the energy of heat appears in the brass button and the deal board.

Now we may conceive that the resistance offered by this platinum wire to the electric current is a kind of *electrical friction;* and that the electrical energy expended in overcoming that resistance is converted into heat, just as muscular energy is converted into heat in the familiar experiment of the schoolboy.

An electric lamp, then, is nothing more nor less than a contrivance to convert the energy of an electric current into

the energy of heat. It must consist of a conductor which, while it allows the current to flow through it, offers nevertheless a considerable resistance to its passage: and the conductor must be of such material that, when raised to a high temperature, it will glow with light.

Electric Light first produced, 1810.—The Electric Light was first produced by Sir Humphry Davy, at the Royal Institution of London, in the year 1810. He employed a battery of 2,000 cells, and he connected the poles of the battery, by means of a stand like this before you, with two carbon rods, which were mounted on the stand. When the two carbon rods were first brought into contact, and then slowly drawn asunder through a short distance, the current leaped across the intervening space of air, and at the same moment the carbons were intensely heated, and shone with a light of dazzling brilliancy.

I can show you this experiment on a small scale. In the next room there is a battery of twenty-six cells, and the poles of the battery are connected, by these two conducting wires, with the two carbons which you see mounted on the frame before you. At present the carbon points are half an inch asunder, and no current is passing. But by turning a screw provided for the purpose I can bring them into contact: they are now touching, and the red glow that you see at the point of contact shows that the current is flowing. I next reverse the movement of the screw, separating the carbon points by about a quarter of an inch, and a brilliant star of white light fills the space between them.

This experiment of Sir Humphry Davy attracted universal attention, and awakened a general expectation that so

brilliant a light would soon be turned to useful account as an ordinary means of illumination. But the expectation was not destined to be quickly realized. The Voltaic Battery, which was the only means known at that time, and for many years afterwards, of producing an electric current, was too

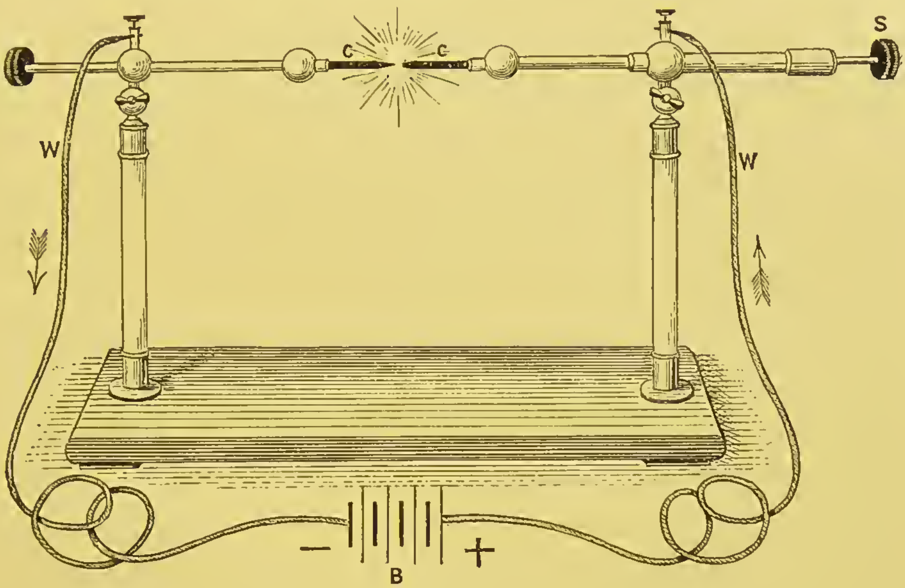

FIG. 44.

SIR HUMPHRY DAVY'S EXPERIMENT.

B Battery
W W Wires from Battery to Carbons.
C C Carbon Rods.
S Adjusting Screw.

costly and troublesome for general use: and although the Electric Light has long been familiar to scientific men as a useful means of research and illustration, it is only since the development of the Dynamo-electric machine, within the last twenty years, that it has emerged from the obscurity of the laboratory, and passed into the wider domain of everyday life.

Two Types of Electric Light.—You will observe, from the experiments I have already shown you, that there are two different methods of producing light from an electric current; in fact, two different types of electric lamp. In the experiment of Sir Humphry Davy, the solid conductor is interrupted, and a narrow stratum of air interposed in the path of the current. The light produced in this way is called an Arc Light. In the case of the platinum spiral there is no interruption in the circuit: the solid conductor is continuous throughout, and a portion of it is made to glow as the current passes through. The light so produced is called an Incandescent Light.

These names are not very happily chosen. The Arc Light is so called from its supposed resemblance to the form of an arc. But the resemblance is more fanciful than real; and, in any case, it is quite a secondary feature in the character of the light. Again, the Incandescent Light has no special claim to that title; because both forms of light are really incandescent, both being produced by the glowing or incandescence of the heated conductor. But life is too short to quarrel about names: and having put you on your guard against any misunderstanding that might arise from the use of these terms, I will take the names as I find them, the Arc Light and the Incandescent Light, and I will tell you something about each.

The Arc Light.—Let me begin by repeating again the experiment of Sir Humphry Davy, which gives us, as I said, what is now known as the Arc Light. I first turn the screw to bring the carbon points into contact; then I reverse the movement, separating them by a short space, and the

light at once bursts forth. But observe, after a few moments, when the apparatus is left to itself, the light gets dim and eventually goes out. The reason is that the carbon points are slowly consumed in the intense heat generated by the current; the distance between them is thus gradually increased; as the distance increases, the resistance offered to the current is likewise increased, and the current gets feebler; at last the resistance becomes so great that the current ceases to pass, and the light dies out.

Hence it is necessary, if we want to maintain the light for any length of time, to keep the carbon rods so adjusted that, notwithstanding the waste that is always going on, they shall remain, nevertheless, at practically the same distance apart. In the apparatus before us such an adjustment may be made by means of this screw, which enables me slowly to advance one of the carbon rods, as the space between them is increased by the process of slow combustion. But when the light is wanted for practical purposes, it is evidently desirable that the adjustment should be made by some kind of mechanism, which shall work of itself without the interventions of any external agency.

Duboscq's Lamp.—Such a piece of mechanism was first invented by Foucault of Paris, and was afterwards improved by Duboscq. It is commonly called Duboscq's Electric Lamp. I have it here on the table; and I will try to give you a general idea of the principle on which it works. The carbon rods, as you see, are so fixed in these brass sockets that they are both in the same vertical line, one pointing upwards, the other downwards, with a short

distance between them. The lower carbon is permanently connected with the positive pole of a battery or Dynamo, and the upper carbon with the negative pole. Within the case of the lamp there is a clockwork arrangement, which you can see through this glass plate; and when the clockwork is set going, the carbons are made to approach each other. When they come into contact the current passes. At the same moment, an electro-magnet within the case is magnetised by the current, and attracts a small iron bar, which is held suspended by a spring just above the poles of the magnet. The effect of this is twofold. First, the movement of the iron bar pulls asunder the carbon points through a short distance, and starts the light; secondly, it pushes in a small knife edge against a toothed wheel, and stops the clockwork.

As the light continues to shine, the carbon points are slowly consumed by the intense heat. The distance between them is thereby increased, and the current gets feebler. Now the electro-magnet, being fed by the current, gradually loses its strength as the current gets feebler, and relaxes its hold of the iron bar. At last, it can hold it no longer, and the iron bar is pulled up by the spring, the strength of which is carefully adjusted beforehand. When the iron bar is pulled up the clockwork is set free, and the carbon points again begin to approach. As they come nearer to one another, the current gets stronger, and the magnet, regaining its force, pulls down the iron bar again, and stops the clockwork. Since this process may go on indefinitely, the light will be maintained until the current is cut off, or the carbons burned away.

New Forms of Automatic Lamp.—So long as the Electric Light was confined to the laboratory and the lecture hall, this lamp of Duboscq, in one form or another, held almost undisputed possession of the field. But the recent development of the Dynamo-electric machine gave a new impulse to invention; and there are now before the world a countless variety of lamps suitable for the production of the Arc Light. You may see them, of various shapes and forms, at the railway stations and in the public squares of nearly all the capitals of Europe, and they are distributed even more abundantly over the great continent of America. Some of them, no doubt, leave much to be desired in point of steadiness and certainty of action; but many of them, on the other hand, work with a degree of smoothness and precision which almost justifies the enthusiastic descriptions by which they are heralded into public notice. I will not trouble you with the details of their construction. Enough it is to say that they all aim at the same end, namely, to keep the carbon points at a constant distance from each other, notwithstanding the fact that they are always wearing away by combustion.

But no matter how perfect the mechanism of these lamps may be, the Arc Light is always, from its very nature, an unsteady light. The distance between the carbon points first increases as the carbons are consumed, then it is diminished when the mechanism comes into play, then it increases again; and so on, indefinitely. Now every change in the distance between the carbons produces a change in the resistance of the arc; and every change in the resistance of the arc produces a change in the intensity of the light.

Thus the light is, of necessity, constantly varying in intensity; and the highest aim of inventors has been to reduce such variation within the narrowest possible limits. Absolute steadiness of the light seems hardly attainable: the most that can be hoped for is a near approximation to steadiness.

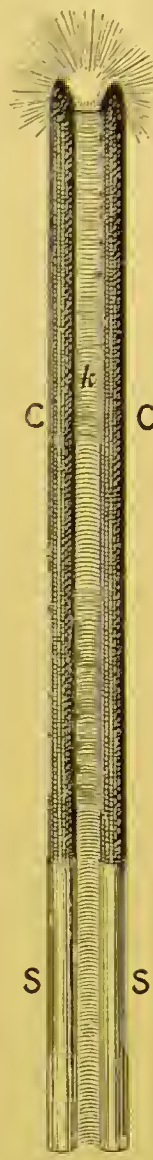

FIG. 45.
THE JABLOCHKOFF CANDLE.
C C Carbon Rods.
k k Insulating Layer of Paste.
S S Brass Sockets to be connected with Battery or Dynamo.

The Jablochkoff Candle.—About twelve years ago, a great sensation was produced by the introduction of a new form of Arc Light, under the name of the Jablochkoff Candle. Monsieur Jablochkoff was an officer in the Russian army; but as soon as he conceived the idea of his Electric Candle he resigned his commission, and came to Paris. Here he took out a patent for his Candle, opened a workshop for the manufacture of it, and in a few months made himself famous as the inventor of a new form of Electric Light.

I have here a few specimens of the Candle. It consists, as you see, of two carbon rods, about ten inches long, placed parallel to one another, and kept at a distance of about a quarter of an inch all along their length, by a solid layer of white pasty matter which acts as a non-conductor. The composition of this paste is an important feature in the manufacture of the Candle: various substances have been tried at different times; but I believe the most effective is now found to be a mix-

ture of baryta and plaster of Paris. The carbon points project about a quarter of an inch beyond this insulating layer; and a small bridge of some conducting material is laid across, to enable the current to pass from one to the other.

When the Candle is mounted for use, one carbon is put in connexion with the positive pole of the dynamo or battery, by means of the brass socket in which it is fitted; and the other carbon is similarly put in connexion with the negative pole. The current, not being able to force its way across the insulating layer that separates the two carbons, passes up through one, then across the bridge, and down the other. The bridge is at once consumed by the heat generated and the Arc Light is startled between the two points. In the intense heat of the Arc, the insulating layer is melted and consumed; and the whole Candle burns slowly away in the course of about two hours. The intensity of the light is equal to from two to three hundred candles.[1]

There is an interesting little bit of scientific history connected with this invention. Jablochkoff had read in text-books on Electricity that the positive carbon is consumed twice as fast as the negative; and he said, "I will provide for that by making my positive carbon twice as thick as my negative, and so they will burn down evenly together." He accordingly made his Candles, in the first instance, with one thick and one thin pencil of carbon; the thick pencil being always connected with the positive

[1] For a full account of the Jablochkoff Candle, see the elaborate work just published by Hippolyte Fontaine, Eclairage à l'Electricité, Paris, 1888, pp. 376–381.

conductor, and having twice as great a sectional area as the thin one.

But this ingenious device did not stand the test of practical experience. On the one hand, the positive carbon did not burn away exactly at the rate which had been calculated upon; while, on the other hand, the negative carbon, offering a greater resistance to the current, became red hot along a considerable portion of its length, and was thus sensibly reduced in thickness, by slow combustion at its surface. Owing to these causes the Candle was found to burn very irregularly, and generally went out at the end of about a quarter of an hour.[1]

The first Candles then were a failure. But the inventor soon found another resource. You may remember I explained, in my last Lecture, that a dynamo can give us currents alternately in opposite directions, or currents continuously in the same direction, according to the mode of its construction. Jablochkoff, then, conceived the idea of using a machine which would give currents alternately in opposite directions. Thus each carbon would be alternately positive and negative: they would therefore be equally consumed, and if made of exactly the same thickness they would burn down evenly together.

This new Candle at first promised to be a great success. It was taken up in Paris, and used instead of gas along the whole length of the Avenue de l'Opéra, as well as on the Place du Théâtre Français, at one end, and the Place de l'Opéra, at the other. In London, too, it was adopted on the Thames Embankment, from Charing Cross Station to the

[1] Id. *ib.*, p. 377.

Houses of Parliament. But it failed to fulfil the high hopes which it had awakened. Perhaps the clearest evidence of its failure is that they have taken down all the Electric Candles on the Avenue de l'Opéra, and I am sorry to say have gone back again to gas.

The cause of the failure is due, I think, in great measure, to the insulating layer of paste. When the current passes across from carbon to carbon, this paste is melted and vaporised, and produces a sort of flame with a varying tinge of colour. Moreover, there seems to be a constant change of resistance, according to the condition of the paste, at any given moment; and this gives rise to a great unsteadiness in the light. At all events, whatever the cause may have been, the Jablochkoff Candle, though at first received with great enthusiasm, has been generally found unsatisfactory; it has been almost completely abandoned in England, and it is not likely to be heard of much more in the history of Electric Lighting.

I should say, however, that the Electric Candle still seems to find favour in France. According to the most recent accounts it is still manufactured, in that country, at the rate of a million and a-half a-year. At Havre, it is used to illuminate the port; and in Paris, it is familiar to all visitors, at the Magasins du Louvre and the Magasins du Printemps. It appears that, between these two establishments, somewhere about 465 Jablochkoff Candles are in daily use. But in the more famous mart known as the Bon Marché, which has recently been fitted up with one of the finest Electric Light installations in the world, there are only 96 Electric Candles, while there are 290 Arc Lights of

the ordinary kind, and 1808 Incandescent Lamps of the Edison type.[1]

The Incandescent Light.—I now come to speak of the Incandescent Lamp. In this form of lamp, the conductor through which the current flows is continuous: that is to say, there is no point in the circuit where the current has to leap across a stratum of air, as in the Arc Lamp. But the resistance of the circuit is so adjusted as to be concentrated on some one part of the conductor, which is thus made to glow with intense heat, when the current passes. The simplest example of such a lamp is the platinum spiral which I have already shown you, and which, I may say, has been before the world for nearly fifty years. The current, coming from a battery of ten cells in the next room, is here conveyed for the most part through a stout copper wire, which offers little resistance, and is therefore only slightly heated: but, at a certain point in the circuit, a spiral of platinum wire is interposed in the path of the current, for a space of two or three inches. The platinum wire offers considerable resistance; intense heat is therefore produced in this part of the circuit; and the wire glows with a rich white light.

This platinum spiral is, in some respects, a very perfect little lamp. Platinum has no tendency to combine with oxygen, even when raised to a high temperature, and no matter how often it is made incandescent, it is not consumed. It glows with light when the current passes; and it returns to its former state when the current is shut off.

[1] See Eclairage à l'Electricité, par Hippolyte Fontaine, Paris 1888, pp. 380, 544–551.

One would almost think that a lamp of this kind should last for ever. But it has one fatal defect. Every metal has its own melting-point, that is to say, a certain definite temperature at which it will melt. The melting-point of platinum is estimated at about 2,000 degrees centigrade; and to yield a really good light it must be raised to the very verge of melting. Hence, in order to get an effective light from incandescent platinum, we must keep it so close to its melting-point that a slight irregularity of the current may, at any moment, cause it to melt, thus breaking the continuity of the circuit, and extinguishing the light.

I should like to bring this point home to you by an experiment, though the experiment involves the sacrifice of my lamp. At present the current flowing through this spiral is carefully regulated, to make it glow with a fairly good white light. But I can increase the strength of the current, either by adding more cells to the battery, or by cutting out some resistance from another part of the circuit. The latter method is the more delicate, and the more convenient for our purpose. You see on the wall a rectangular frame containing twelve stout carbon rods. This is called a resistance-board. At present these carbon rods are part of the circuit, so that the current must flow through them all, one after another. But by turning a handle, I can cut out two or more at pleasure, and so reduce the resistance by small degrees.

I now turn the handle, and cut out two carbon rods. The resistance is slightly reduced, the current becomes stronger in proportion, and you see the platinum spiral shines with increased brightness. I advance the handle

another stage, and cut out two more carbons. The platinum spiral is more brilliant still; but its brilliancy lasts only for a moment; its melting-point has been reached; the circuit is broken; and the light disappears.

You will say, perhaps, that we might avoid this danger if we contented ourselves with a less brilliant light. Quite true: but that is just what we will not do. Having once seen what a brilliant light the electric current can give us, we will not be content with a platinum spiral that gives us only the light of two or three candles. Hence, after many ingenious attempts of Mr. Edison to produce an effective lamp, first with platinum alone, afterwards with an alloy of platinum and irridium, this form of lamp has been reluctantly abandoned, at least for the ordinary purposes of illumination.

Carbon versus Platinum.—Now the property that platinum wants is possessed in a very high degree by carbon. I have already said that carbon cannot be melted by any kind of artificial heat yet known. Hence it was recognised long ago that, if we could substitute for this platinum spiral a slender rod of carbon, we might raise it to the most brilliant incandescence without any fear of melting it. But unfortunately carbon has another property which would be fatal to such a lamp. It would not melt, but it would be consumed. Carbon, when raised to a high temperature, has a great affinity for oxygen; and if our carbon lamp were exposed to the air, as we have exposed our platinum lamp, the carbon, when raised to incandescence, would combine with the oxygen of the air, to form carbonic acid, and would be burned away in a very short time.

The remedy for this defect is easy to see, and was tried so long ago as the year 1845, by an American inventor named King. He got a thin pencil of carbon, mounted it on a frame within a glass vessel, and then exhausted the air from the vessel, by a process similar to that by which a Torricellian vacuum is produced in a barometer tube. This lamp, however, was a failure. The carbon pencil received the electric current by means of a metal rod passing through the glass vessel; and sufficient air soon found its way through the joint thus established to cause the combustion of the carbon.

I may say that practically no progress was made with this form of Electric Light, from the time of King until the year 1879, when Mr. Edison of New York, and Mr. Swan of Newcastle, startled the world by the production of those beautiful incandescent lamps which are inseparably associated with their names. Other inventors quickly appeared in the field; numerous patents were taken out; and various claims to priority were advanced. I need not dwell upon these claims, or on the controversies to which they have given rise. It is enough to say that the incandescent lamp, which had awakened such hopes, and such fears too, when first announced to the world, was rapidly brought to a high degree of perfection; and by the time of the Paris Electrical Exhibition, in 1881, it was already fully established as a magnificent success.

A Perfect Vacuum.—The name of Mr. Crookes of London is not often mentioned in connexion with electric lighting; and yet Mr. Crookes has contributed, in no small measure, to the production of the incandescent lamp in its present

form. The lamp consists of a thin filament of carbon mounted in a glass globe from which the air has been exhausted. In its essential principle, therefore, the lamp does not differ from the lamp invented by King forty years ago. But King's lamp failed for want of a good vacuum; and Mr. Crookes is the man to whom we are mainly indebted for the almost perfect vacuum of the modern lamp. The history of this matter is interesting and curious.

Mr. Crookes was engaged, between the years 1873 and 1878, in making experiments with his well-known radiometer. For these experiments he required a vacuum far more perfect than any which had been previously known. He therefore applied his rare powers of invention and contrivance to the improvement of Sprengel's mercurial air-pump. And so great was his success that we are now in possession of an air-pump which, with ease and certainty, can reduce the density of the air within a glass globe considerably below the millionth of an atmosphere.

With such a vacuum placed at their disposal, the difficulties in the way of inventors, occupied with the development of the Electric Light, were already half conquered: and accordingly it is not wonderful that, between the year 1878 and the year 1881, a number of different lamps, with more or less claims to originality of invention, should have been brought into public notice. The most successful of these lamps were those of Mr. Edison and Mr. Maxim in America, and of Mr. Swan and Mr. Lane-Fox in England.

Incandescent Lamp with Carbon Filament.—The essential elements of an incandescent lamp, as now made, are a thin filament of carbon, a glass globe, and a perfect vacuum.

Here is one of the most recent construction: but you will see the details more distinctly on the diagram before you. L is the glass globe from which the air has been almost completely exhausted; C is the carbon filament; *b b* represent the platinum wires, which pass through the glass, and are

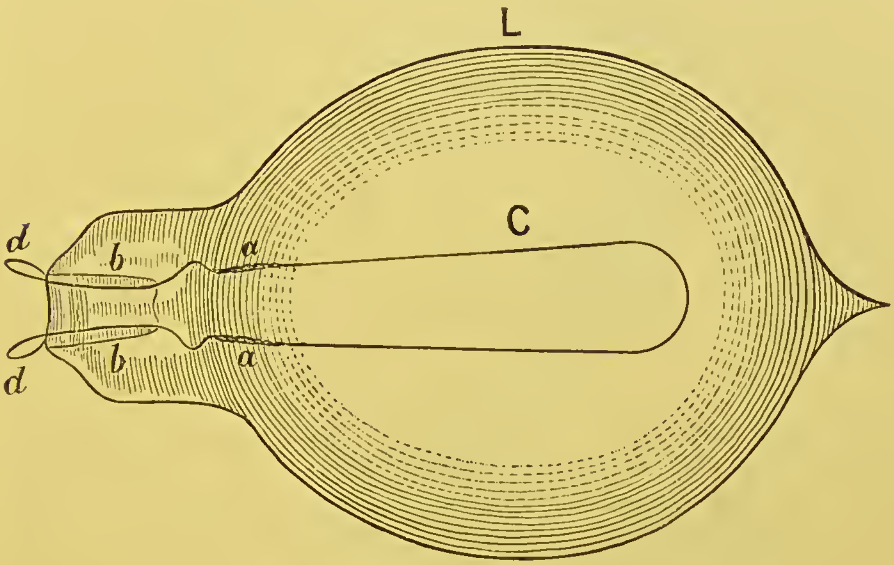

FIG. 46.

THE INCANDESCENT LAMP.

L Glass Globe exhausted of Air.
C Thin Filament of Carbon.
b b Platinum Wires attached to Carbon Filament at *a a*, and looped outside the Glass at *d d*.

formed into loops outside at *d d*; and *a a* show the points of attachment connecting the carbon filament with the platinum wires.

In order to connect the platinum wires with the opposite poles of a Dynamo or Battery, it is usual to provide for each lamp what is called a Holder. The Holder of the Swan lamp, which you see here on the table, and which is also

represented in the diagram on the wall, is extremely simple. It

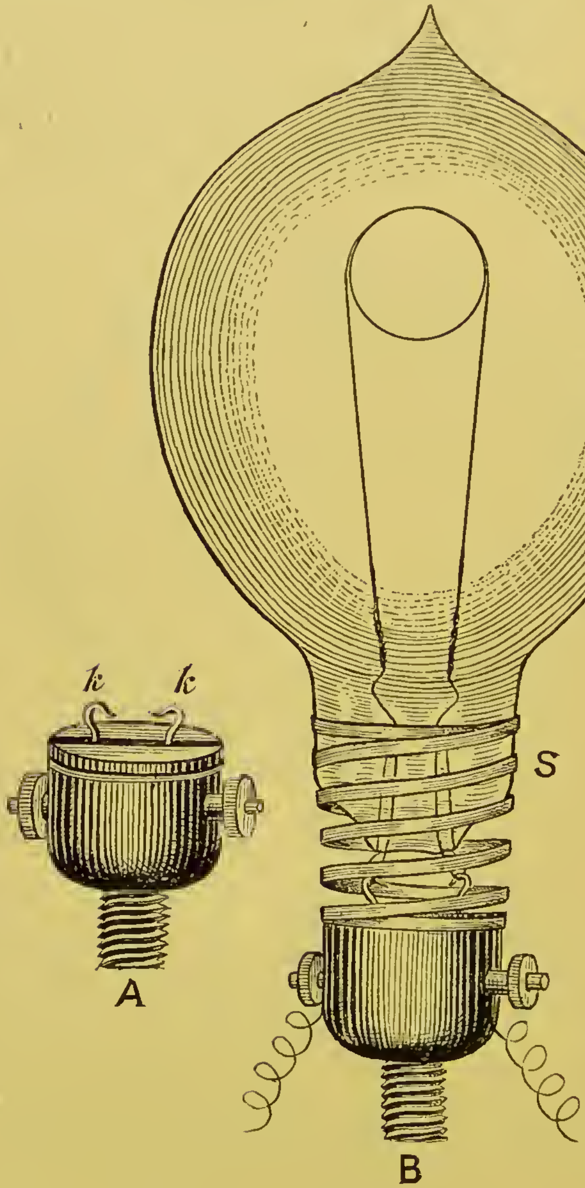

Fig. 47.

Incandescent Lamp and Holder.

A Holder showing Hooks at *k k*. | B Lamp on Holder showing Spring at S.

consists of a button of ebonite or hard wood, with two binding

screws, to which the wires from the Battery are attached, and which are themselves connected with two hooks, *k k*. You see how easily the lamp may be fitted on to these hooks, by means of the platinum loops which are left exposed outside the glass globe. But to secure more perfect contact, a spiral spring is interposed between the Holder and the lamp, which tends to push them away from one another, and thus maintains a steady pressure at the points of contact. I now take a lamp and fit it on to the Holder, and you see it ready for use.

Preparation of the Carbon Filament.—Next to the vacuum, which is now always produced by one form or other of the mercurial air-pump, the most important feature in the lamp

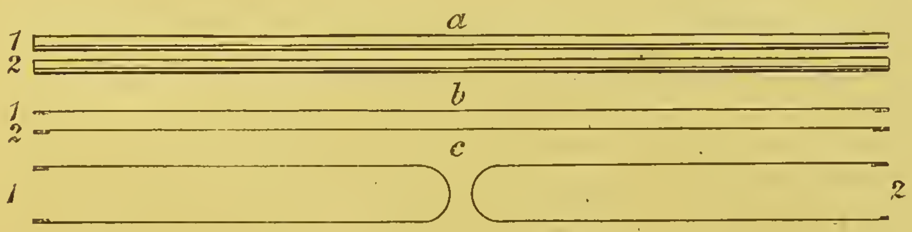

FIG. 48.

PREPARATION OF FILAMENTS FROM BAMBOO CANE.

a Flat Strips of uniform Character.
b The same narrowed down to thickness of a Thread.
c The same bent into Shape and ready for Carbonisation.

is the carbon filament. This filament is variously made. The most essential property, recognised by all, is that it should be of uniform thickness and uniform structure throughout its whole length, so that it shall offer, at every point, exactly the same resistance to the passage of the

current. Mr. Edison after numerous experiments with a great variety of vegetable fibres, selected the bamboo cane as the most suitable for his purpose.

Having first removed the hard silicious outer coating, he prepares a number of strips perfectly flat and straight, of the required length, as shown in the diagram at *a*. Each of these he shaves down to a uniform thickness along its whole length, with instruments which he has specially devised for the purpose. He then narrows them to the fineness of a thread, leaving a small projecting piece at each end. They are thus reduced to the condition shown at *b* in the diagram. Lastly, these fine threads of bamboo fibre are bent into shape as shown at *c*, and fitted into moulds to be carbonised.

Mr. Swan, in the first instance, used cardboard as the material from which he manufactured his carbon filament; afterwards he tried bibulous paper, which he treated with dilute sulphuric acid; but he finally settled down to ordinary cotton thread as giving the most satisfactory results. He steeps the cotton thread in dilute sulphuric acid, giving it thereby somewhat of the character of parchment, then twists it into the shape required, and prepares it for carbonisation. This is the process, I believe, now commonly followed by the Edison-Swan Company. The carbon filament produced by it is said to be very tough, and as hard and stiff as a metallic wire.

In the process adopted by the Anglo-American Brush Company, cotton wool is the material employed. It is first dissolved in chloride of zinc, and being slightly heated is reduced to a viscous or semi-fluid condition. It is then

forced through a small orifice under the pressure of a head of mercury, and, coming out in a thread-like form, is received in a vessel of alcohol, where it solidifies. Lastly, it is placed in another vessel of alcohol, which dissolves all impurities; it is then dried and carbonised.[1]

The process of carbonisation is practically the same for every kind of filament. The vegetable fibre, having been prepared in any of the various ways above described, is packed in powdered charcoal in a closed vessel, and then gradually raised to a white heat, at which it is kept for several hours.

When the carbon filament is ready for use, the ends of it are carefully attached to the ends of two platinum wires, and it is introduced into a glass globe, the neck of the globe being raised to a melting temperature and closed in round the platinum wires, so as to form a perfectly air-tight joint. It only remains then to exhaust the air from the globe, which is done by means of a glass tube, which serves to connect it with a mercurial air-pump.

During the process of exhaustion a current of electricity is sent through the carbon filament, which is thereby raised to incandescence, and freed from the air and other gases that might otherwise have remained shut up within its pores.

[1] It is interesting to note that this process has been the subject of a protracted law-suit, in which the Edison-Swan Company were the plaintiffs, and the Brush Company were practically the defendants. It was contended on the part of the Edison-Swan Company, that they had the exclusive right to manufacture lamps with carbon filaments. But the learned judge refused to admit this claim, and gave judgment in favour of the Brush Company. The history of the incandescent lamp was very fully brought out during the progress of the trial, and is set forth with great clearness in the luminous judgment of Mr. Justice Kay. See The Electrician, May, June, July, 1888.

When the exhaustion is complete, the tube connecting the globe with the air-pump is removed, and the orifice in the globe is closed in the blow-pipe flame.

Light without Heat?—There are some questions of practical interest connected with the Electric Light on which I should wish to say a few words, before bringing this Lecture to a close. First, I may notice a general impression which seems to prevail that, in the case of electric illumination, we have light without heat. Now I have shown you that, in both forms of the Electric Light, the carbon becomes luminous simply because it is made intensely hot. You have seen, in fact, that when a platinum wire is used instead of a carbon filament, in the incandescent lamp, there is danger of melting the wire, though its melting-point is somewhere about 2,000° C., which is higher than that of any other metal.

Again, in the arc lamp, the heat of the carbon points is absolutely the greatest artificial heat known. To give you some idea of this intense heat, I turn on the current to this arc lamp on the table, and now when I hold a stout platinum wire close to the positive carbon, it melts like sealing wax in a candle flame. A steel rod, held in the same position, sends out a brilliant shower of sparks in all directions. It is therefore an error to say that in either kind of electric lamp we have light without heat.

Nevertheless, there is an important germ of truth in the common belief. If you look closely at the filament of an incandescent lamp, you will see that, although three or four inches in length, it is exceedingly thin. It has, therefore, a very small volume: the volume of an ordinary gas flame is

probably several hundred times as large. Hence though the intensity of the heat in the filament, that is, its temperature, is very great, the quantity of heat is comparatively small. It has been estimated that, for the same amount of illumination, a gas flame gives out more than fifteen times as much heat as an incandescent electric lamp, and wax candles more than twenty-five times as much. Similarly in the case of the arc light, the incandescence of the carbon points is confined to a very small volume, and the quantity of heat generated is proportionally small.

The Arc Light and the Incandescent Light compared.— Next, perhaps, you would like to hear some opinion as to the relative merits of the arc lamp and the incandescent lamp. I would say that each is excellent in its way; but they are suited for quite different purposes. First, let me say something of their relative cost. For a given expenditure you can get eight or ten times as much light from the arc lamp as you can from the incandescent lamp. Every horse-power in your engine will maintain about eight incandescent lamps, giving a light of sixteen candles each, or say a hundred and thirty candles in all: whereas the same power with an arc lamp will give an average light of a thousand to twelve hundred candles.

The arc light, however, is quite unsuited to the interior illumination of houses. It is too dazzling and it is too unsteady; perhaps I should add that, owing to the predominance of blue and violet rays in the arc light, it gives a weird and haggard appearance both to people and to things. On the other hand, it is admirably fitted for all kinds of illumination out of doors; for the illumination of streets and

railway stations, of public gardens, docks, and harbours, in a word, of all places where people congregate or work is to be done.

The incandescent lamp comes in most efficiently just where the arc lamp fails. It gives a rich soft light in which brilliancy and steadiness are combined, and is admirably suited for interior illumination. It is pre-eminently the light for public institutions of every kind; museums, libraries, and picture galleries, hotels and theatres, shops and factories; and I may say it is the ideal light in private houses and on ship-board. Let us compare it, for a moment, with the other modes of illumination at present in use.

Comparison with other kinds of Light.—Every other artificial source of light, whether gas, or candles, or oil, takes out of the air the oxygen which is necessary for the support of life, and gives back, in return, carbonic acid, which tends to produce suffocation: whereas the incandescent lamp takes nothing from the air, and it gives nothing to it but pure and simple light. Again, the incandescent lamp produces far less heat, as we have seen, for a given amount of illumination, than other sources of light. Once more, oil and candles and gas often produce a disagreeable smell, and always produce more or less smoke, which discolours the walls and ceilings of your rooms, injures your paintings and the bindings of your books, and disfigures every kind of decorative work. The incandescent lamp produces no smoke, and what to many is, perhaps, even more important, it produces no smell.

A very remarkable testimony to the healthfulness of the incandescent lamp, as compared with gas, was given by

Mr. Preece, at the Meeting of the British Association recently held in Bath. About two years ago, the Electric Light was introduced into the Central Post Office Savings Bank, in London; and since that time, the leaves of absence, on account of illness, of members of the staff, have been reduced by an amount equal to an average of two days a year for each person. This, he said, was equivalent to a gain to the service of the time of eight clerks, and represented a saving of about £640 a-year in salaries.[1]

As regards the danger of fire, it is not easy to exaggerate the extraordinary safety of the incandescent lamp. I would only call your attention to one fact. In dealing with gas and candles, we are dealing with a naked flame, whose function it is to set fire to whatever touches it; in the case of the incandescent lamp, we are dealing with a light shut up in a prison house of glass, and if we chance to break the glass, we at the same moment put out the light.

Is the Electric Light now available for use?—But the most important practical question still remains behind: Is the Electric Light at present really available for use, so that we may have it, if we choose, without reasonable fear of disappointment? This is a question I must answer in parts; and I would ask you to remember that I express only my own opinion, founded on such information as I have had acccss to. First, as regards the arc light, it is perfectly available for all purposes of out-of-doors illumination; and you can have it when you please, with certainty, with efficiency, and with economy.

[1] See Address to the Mechanical Section of the British Association, 1888, by W. H. Preece, F.R.S., President of the Section.

Secondly, with respect to the incandescent light, I would say it is available for every public institution and for every private house that is large enough, or rich enough, to afford the expense of a separate installation. Where a large number of lights, say one or two hundred, are required for several hours every day, I believe that a separate installation may be set up and maintained with economy, as compared with other modes of illumination. Hence I hope to see the Electric Light established here in our new Museum and in the National Library, as well as in the National Gallery and the Museum of Natural History. This splendid group of buildings, designed to be a great centre of education and culture for the people, offers a field for the introduction of the Electric Light which, so far as I know, stands almost unrivalled.

In like manner, an Electric Light installation may be established with economy in factories and workshops, in theatres, clubhouses, and large hotels. In private houses, on the other hand, where the number of lights required would be less than a hundred, a separate Electric Light installation would probably be found more costly than other means of illumination. But it would be a luxury: and I can say, with confidence, that this luxury is now available for every one who may wish to have it, and can afford to pay for it.

Lighting from a Central Station.—So much for separate installations. A question of still wider interest has probably suggested itself to most of you: Is it possible to supply the Electric Light to all the houses of a given area, from a central station, as gas is now supplied? This is a problem which is just now the subject of experiment on a large scale:

and when a practical question has been submitted to the test of experiment, it is wiser, I think, not to prophesy until we know the result. I may tell you, however, what has been already done. About two years ago, a central station was established close to the Grosvenor Gallery, in London; and, at the present moment, this station supplies electric currents for about 30,000 incandescent lights, scattered over an area of somewhat more than a mile radius. This is the largest experiment of the kind, so far as I know, that has yet been carried out in England; but how far it may be regarded as a practical success it is impossible to judge until we know, upon sufficient authority, the exact facts connected with the working of the system.

Transformations of Energy.—And now, in conclusion, let me remind you, even at the risk of repetition, that in setting before you this slight sketch of the history and development of the Electric Light, I have given you, at the same time, as I believe, a striking illustration of those wonderful transformations of energy that are for ever going on around us, both in the operations of Nature and in the works of man. In my last Lecture, I sought to bring home to you that the Dynamo is nothing more than a machine for converting the energy of mechanical motion into the energy of an electric current: and in my Lecture to-day I have shown you that the various forms of electric lamp are only so many contrivances for converting the energy of the electric current into the energy of heat and light.

If I were to trace back the history of these transformations further towards their source, we should find that the mechanical energy which drives the Dynamo is derived from

the stored-up energy of coal; and the coal comes from the vegetation of a long past time; and that ancient vegetation was quickened into life by the energy of the sun's rays. Thus it would seem that this beautiful light, which the Science of our time has called forth to illuminate our streets and our houses, does but bring back to us the energy of the primeval sun, which for long ages appeared to be lost, but was in fact carefully stored up for our use; and the saying of the Roman poet, "Omnia mutantur nihil interit," receives a deeper and a fuller meaning than even he himself would probably have attached to it.

THE GLACIERS OF THE ALPS.

A LECTURE

TO A YOUNG MEN'S SOCIETY.

"Mont Blanc is the monarch of mountains;
They crowned him long ago
On a throne of rocks, in a robe of clouds,
With a diadem of snow.
Around his waist are forests braced,
The Avalanche in his hand;
But ere it fall, that thundering ball
Must pause for my command.
The Glacier's cold and restless mass
Moves onward day by day;
But I am he who bids it pass,
Or with its ice delay."

BYRON.

A LECTURE

ON

THE GLACIERS OF THE ALPS.

THE Glaciers of the Alps have a wide and many-sided interest. While they are an object of fond devotion to those who dwell habitually among them, they attract from distant countries, with a sort of fascination, men of the most opposite pursuits in life. The poet loves to haunt those lonely solitudes of ice, and there, gazing on the wild and changeful face of Nature, "feed on thoughts that voluntarily move harmonious numbers." The daring mountain climber, lured by the love of adventure, scales their glittering slopes, nor rests till he has reached their highest summits, crowned with a canopy of perpetual snow. The philosopher, again, finds in the Glaciers of the Alps a key to the past history of our globe, and recognises, in those ponderous masses of moving ice, a mighty engine by which the rough and furrowed form of many a mountain chain was sculptured out in ages long gone by.

But the interest of the Glaciers is not for these alone; favoured children of earth, endowed with rare gifts of mind, or powers of body. The instinctive love of nature and her works is common to us all: and the crowds of eager tourists who, summer after summer, darken the snow fields of the

Alps, climbing the steep moraine, and peering into the caverns of ice, give proof, if proof were wanted, that this pure and healthy instinct is not altogether extinguished by the absorbing ambition or the distracting cares of ordinary life.

I shall not attempt to picture to you, this evening, the singular and attractive beauty of those pathless regions of ice and snow, lifting up their lofty summits against the clear blue sky above, and stretching away to the green meadows and picturesque hamlets of the valleys below. This task more fitly belongs to the artist and the poet. Neither do I mean to entertain you with a story of perilous adventure and hair-breadth escapes. Narratives of this kind, told not unfrequently with graphic power of language, and illustrated with no small artistic skill, may be found, without stint, in the records of the Alpine Club. Mine will be the humbler task of setting before you some account of the origin and nature of Glaciers, and of sketching out the functions they fulfil in the physical history of our globe.

Cold of High Altitudes.—I need hardly tell you that the higher we ascend in mountain regions, the colder the air becomes. But this fact, though familiar, is well deserving of careful consideration, for it is closely bound up with some of the most interesting and important principles of physical science. Why is it that the air gets colder the nearer we go to the sun, the great source of heat? There are two principal reasons, and I trust I shall not weary you if I dwell for a few moments upon each.

First, the air is not heated directly by the sun, but by the earth. The bright, luminous rays of the sun pass through

our atmosphere without imparting to it any considerable amount of heat. This you may easily prove for yourselves by a very simple experiment. Stand in the bright sunshine of a clear, cold day, and realise, for a few minutes, the genial heat which the sun's rays are carrying through the air around you. Then step aside into the shade, a few feet off, and you will at once feel convinced how little of that heat has been imparted to the air itself, though it has been streaming through it, perhaps, for hours.

The earth, however, like your body, is warmed by these same rays; and when the earth grows warm, it becomes, in its turn, a source of heat, and sends forth rays of its own back into the atmosphere again. Now, these rays that come back from the earth are not luminous like those of the sun: they are dark or obscure rays of heat. And the air, which could imbibe little heat from the bright rays of the sun, imbibes it largely from the dark rays of the earth. Thus it is that while the air is indebted for its warmth to the sun, it receives that warmth not directly from the sun itself, but from the earth, which is heated by the sun.

This is a wise and beneficent provision of nature. Suppose, for a moment, that the atmosphere were so constituted that it could absorb heat from the luminous rays of the sun. The process would begin when the rays first enter our atmosphere at a height, say, of a hundred miles; it would continue throughout their whole course; and thus the heat of these rays would be almost wholly exhausted before they could reach the surface of the earth. The consequence would be, that the whole earth would be far colder than the arctic regions now are, and would be, therefore, utterly unfit

for human habitation. But, in the present dispensation of Nature, the atmosphere, in a manner, entraps the sun's heat for our use and benefit, allowing it to pass in freely from without, but not allowing it to pass freely back into space.

Bearing in mind, then, that the air receives its heat directly from the earth, let us consider what is the consequence of this fact on its temperature at high altitudes. In the first place, the radiant heat coming from the earth must, as a rule, pass through the lower strata of the atmosphere before it reaches the higher. As it ascends, it suffers loss, at every moment, by absorption, and therefore, the higher it rises the feebler it becomes. Further, the air of the higher regions being much more rarified than the air below, its power of absorbing heat is proportionately diminished. Thus you see one clear reason why the upper strata of the atmosphere are colder than the lower; the radiant heat that reaches them is less, and their power of absorbing that heat is also less.

The second reason will not detain us long. When air expands, heat disappears; when air is compressed, heat is developed. I will ask you to take these statements on trust, for the present; because a discussion of them would lead us too far from the subject in hand. But I will offer, in passing, one brief word of explanation, which may, perhaps, serve to stimulate, though it cannot quite satisfy, intelligent curiosty. When air expands, heat disappears; because, in fact, heat is the agent that produces the effect. It expends its own energy in doing a certain work, that is, in overcoming the pressure of the atmosphere; and the energy so expended ceases to exist as heat. Hence, after expansion

has taken place, the total quantity of heat, present in the air, is less than it was before.

On the other hand, when air is compressed, some kind of energy, from without, must be expended in compressing it. The energy so expended vanishes, and heat appears in its stead. In other words, the energy expended has been converted into heat. Thus, after compression, the total quantity of heat present is greater than before.

Now, picture to your minds the great chain of the Alps, with an average height, let us say, of 11,000 feet; and, to fix our ideas, let us suppose that the wind is blowing from the south. The air, charged with the moisture of the Mediterranean, strikes against the base of this mountain barrier; it is tilted up, and begins to ascend the slopes; as it rises it expands; heat is consumed by the fact of expansion; and, long before the highest peaks are reached, the warm atmosphere of Italy has, by its own inherent action, been reduced to freezing temperature. Meanwhile, the vapour that it bears along has been condensed into water; and, when the freezing-point is reached, the tiny particles of water gradually pass into the solid form of ice. Then begins that wonderful and mysterious process by which the infinitesimally minute molecules of ice are built up into tender crystals of snow; and these crystals, clinging together, form flakes; and the flakes fall thick and heavy, covering the slopes and summits of the mountains with a mantle of dazzling white.

And now the air, having swept over the towering crests of the mountain rampart, is borne downwards into the valleys of Switzerland. As it descends, it is gradually condensed by

the increasing pressure of the atmosphere above it; condensation develops heat; and, by the time it has reached the cities of the plain, it is genial and pleasant once again. Thus we learn how the same current of air which is warm when it leaves the plains of Italy, and warm again when it reaches the valleys of Switzerland, becomes, in the interval, so cold, from the very nature of the journey it makes, as to leave a thick covering of snow on the intervening mountain chain.

We have now, as I hope, mastered one important phenomenon to which the existence of Glaciers is due, and we have traced that phenomenon to its cause. The phenomenon is simple and familiar: that the higher we ascend in mountain regions the colder the air becomes. The cause is twofold: first, the air of the higher regions receives less heat from the earth; and, secondly, the air that comes up from the plains expands as it rises, and is chilled by the fact of expansion.

Formation of Glaciers.—But a cold atmosphere, though a necessary condition for the production of Glaciers, is not in itself sufficient. There must be also an abundant supply of snow, which we may regard as the raw material of which Glaciers are made. When the yearly fall of snow is inconsiderable, it is melted away by the summer's sun, and no permanent Glacier can be established. But when the snowfall of the year is great, and the cold of the air intense, then the snow can bid defiance to the powers of the sun. His rays, no doubt, are fierce enough in summer, as we may learn from the sunburnt and blistered faces of Alpine travellers: and the bright colours of the mountain flowers, which bloom in the hidden nooks and fissures of the rocks,

bear witness, in a more pleasing way, to his genial warmth. But the sunny days are too few, and the summer too brief, and the piles of winter's snow offer a gentle but indomitable resistance. Hence, in the higher regions of lofty mountain chains, the ground is covered with snow the whole year round, except where the projecting crags and peaks are too steep for the snow to lie on them. These are the regions of perpetual snow; and the imaginary line that bounds them is called the limit of perpetual snow, or, more simply, the snow line.

The position of this line, that is to say, its height above the level of the sea, is very different in different countries. It depends, as you will easily understand, not on the temperature only, but also on the quantity of snow that falls. In the Alps the snowfall is great, owing to the moisture of the climate. The snow line on the southern side is, speaking roughly, about 9,000 feet, and on the northern side about 8,000 feet above the level of the sea. Beyond these limits the snows of winter are piled up from year to year, and constitute, as it were, the vast storehouse of a system of Glaciers which, for number and extent, are unequalled by those of any other country in Europe.

Since a new stratum of snow is spread out each winter over the whole surface of the higher Alps, and each succeeding summer melts away but a part of it, you might suppose, perhaps, that the height of the mountains must increase from year to year, and from age to age. But it is not so. As the vast pile grows up, the weight of the mass above presses down, with enormous force, on the strata underneath, which at length are, in a manner, squeezed out from below, and

begin to move slowly down, in all directions, over the slopes and valleys of the mountain chain. These moving masses are the Glaciers of the Alps. We have sought them out, at their source, in the eternal fields of snow; we have now to follow them in their downward course, and learn something of their history.

Transition from Snow to Ice.—As the Glacier moves down into the valley, it passes from snow into ice by a process not unlike to that by which a schoolboy makes a snowball. He takes a mass of snow and presses it firmly together, while, at the same time, the surface is partially melted by the heat of his hand. In a few moments, the mass becomes much harder, and more compact than ordinary snow, but is yet far from having the hardness and density of ice; and with this most schoolboys are content. But, if mischievously inclined, these practical philosophers may be seen taking special means to increase the pressure more and more; and adding fresh snow as the mass is reduced in size, they produce, in time, a ball which differs little in quality from pure ice.

Now, the snow of a Glacier is subjected, as we have seen, to enormous pressure; and as it moves on, under the influence of this pressure, it is exposed to the heat of the sun which melts it at the surface. Thus we find in the Glacier, on a colossal scale, the two conditions of the schoolboy's snowball; and accordingly, in the Glacier, as in the snowball, the loose, incoherent snow is gradually converted into dense and massive ice. By means of a tunnel, artificially cut into the Glacier, at its lower end, the traveller is able, in some places, to penetrate far into the depths of the ice; and it is interesting to compare its rock-like texture, and

beautiful blue tint, with the powdery appearance and dazzling whiteness of the snow from which it is derived.

Hence we are to conceive the snow fields of the Alps as consisting of two parts, widely different in character. First, there is a vast expanse of snow, which covers the rounded summits and steep slopes of the higher mountains, and fills the great basin-like hollows from which the valleys take their rise. This part of the snow field is called by the Germans *Firn*, by the French *Névé*: there is no name for it in the English language. The snow that falls here has generally a temperature much below the freezing-point of water. It is dry and powdery, like fine dust. Such snow may sometimes be seen in our own country, on a very cold day in winter. You may recognise it at once by the fact that it will not cohere, and you cannot make a snowball of it.

The first effect of the summer sun, in the higher Alps, is to raise the temperature of this snow, and then to melt it at the surface. The water thus produced trickles through the mass, and coming into contact with the colder snow beneath, is soon frozen again; while the film of moisture that covers the surface is also frozen, at night. By these operations the snow, to a certain depth, is partially converted into ice, and is thus brought into a crisp and moderately firm condition. In this state it is easy and pleasant to walk upon. But where the sun's rays are shut out, for the greater part of the day, by a projecting cliff, the snow remains permanently in the state of a loose powder, into which the traveller, at every step, sinks down below his knees.

So much for the *Firn* or *Névé*. From this we must dis-

tinguish the Glaciers proper, which, taking their origin from the *Firn*, pass gradually into dense, transparent ice, and stretch away for miles below the snow line, filling up the valleys to a height of several hundred feet.

Motion of Glaciers.—A Glacier, then, is a massive stream of ice, which is ever moving slowly down from the snow fields of the higher Alps to the warmer atmosphere of the valley, where it gradually melts away and disappears. Like a river it follows the windings and assumes the form of the channel through which it moves, spreading out into an expansive plain in the wider basins of the valley, and crushing itself between the projecting rocks in the narrow passes. This unceasing, onward motion is one of the most wonderful phenomena in Nature. To the casual observer the Glacier not only seems at rest, but it seems as fixed and immovable as the giant mountains by its side. Nevertheless, the poet's words are rigorously true,

> "The Glacier's cold and restless mass
> Moves onward day by day;"

and the evidence of this motion, accumulated during the last hundred years by the researches of travellers and scientific men, is very complete and very interesting.

In the year 1788, the famous Swiss Naturalist, De Saussure, with a large party of guides, passed a fortnight on a lofty shoulder of the Alps, called the Col du Géant, just below the summit of Mont Blanc. On coming down, they left a ladder, fixed in the Glacier, at a well-known point of the descent. Fragments of this ladder were found by Forbes, in the year 1832, about three miles further down the valley.

Thus it would seem that this part of the Glacier had moved three miles in forty-four years, or at the rate of from three to four hundred feet a year. Again, in 1827, Hugi, another Swiss philosopher, erected for himself a hut on the lower Aar Glacier, near the Grimsel. He came back in 1830, and again in 1836, and on each occasion he found that the hut had moved further down the valley. Finally, at the end of fourteen years, in 1841, it was found to have moved altogether about 4,900 feet from its first position. This would represent an average yearly motion of 350 feet.

Still more exact are the observations of Agassiz on the same Glacier. In the summer of 1841, having provided himself with iron boring rods, he pierced the ice at six places to a depth of ten feet, in a straight line right across the Glacier, and at each boring he drove in a wooden stake. The position of this row of stakes he then determined accurately, in reference to fixed points on the mountains, at either side. When he returned, in the month of July of the following year, he found that the whole row of stakes had moved sensibly down from between the two fixed points. Some had moved more, others less. By careful measurement he ascertained that the greatest advance was 269 feet, the least 125.

Observations of Professor Forbes.—But it is to James David Forbes, formerly Professor of Natural Philosophy in the University of Edinburgh, that we are mainly indebted for the varied and accurate knowledge we now possess regarding the motion of Glaciers. He was the first to show, in 1842, that by means of a theodolite, the motion of a Glacier may be made sensible to the eye from day to day,

and even from hour to hour. The scene which he chose for his labours, and which still continues a favourite spot for the study of Glacier phenomena, was the well-known Mer de Glace, so called from its resemblance to a frozen sea. This is an enormous Glacier, which descends from a noble amphitheatre of mountains belonging to the group of Mont Blanc, and, after a course of many miles, forces its way through a narrow gorge, close to the beautiful village of Chamouni. Here the Professor remained for several weeks, and by accurate measurement determined the exact rate of advance of every part of the Glacier. The result of his observations I will tell you by-and-by; but I should wish first to give you some idea how the motion of a Glacier may be made sensible to the eye in the course of a few hours.

A theodolite, as I daresay you know, is practically a telescope mounted on a stand; and for the purpose of exact observation the eye-piece of the telescope is provided with two fine spider threads, which cross one another at right angles. Planting the instrument on the mountain side, and looking through the telescope, straight across the Glacier, an observer is able, without difficulty, to get some well-defined peak of ice to coincide with the intersection of these two cross-threads. This done, the instrument may be left fixed in its position for three or four hours. On looking through the telescope, at the end of that time, it will be seen that the peak of ice no longer coincides with the intersection of the threads, but has advanced sensibly across the field of view. From careful observations made in this way, and often repeated, it has been shown that the maximum motion of the Mer de Glace, in passing through the gorge, is about

three feet a-day in summer, and about half that distance in winter.

The Motion of a Glacier like the Motion of a River.—The great truth established by Forbes, and confirmed by all subsequent observers, is the close analogy between the motion of a Glacier and the motion of a river. Of course the rate of motion is widely different. An advance of three feet a-day, or an inch and a-half in the hour, is very rapid motion for a Glacier; whereas a velocity of two or three miles an hour is not unusual for a river. But, except for this great disparity in the rate of motion, it would seem that a Glacier deports itself, in all respects, exactly like a river. The valley through which it flows may be regarded as the bed of this ice-stream; and, like a river, it everywhere accommodates itself, as we have seen, to the shape and form of its bed. Like a river, too, the ice-stream forces its way rapidly along through the narrow passes, and moves at a sluggish pace where the wide and open valley affords an ample channel.

Again, it is well known that, in a river, the current is more rapid near the centre of the stream than it is near the banks, and more rapid at the surface than at the bottom. The reason of this difference may be easily understood. The friction of the water against the sides and floor of the channel through which it flows, acts as a retarding force; and this retarding force is most effective on those portions of the stream that come nearest to its action. Hence, the edges of the stream are more retarded than the centre, the lower depths more retarded than the surface.

Now, let me recall to your minds the experiment of Agassiz. You will remember that, in the summer of 1841,

he planted a number of stakes, in a straight line across the Glacier of the Aar. In July, 1842, he found that all the stakes had moved a considerable distance down the valley, some more, some less. But I have yet to tell you the appearance they presented when seen from the mountain side. The straight line of stakes was changed into a curve, and the bend of the curve was directed down the valley. It was evident, at a glance, that the stakes near the centre had advanced more during the year than those which were near the mountains on either hand; and, consequently, that the centre of the Glacier was moving faster than the sides.

This result has been repeatedly confirmed by other observers; more particularly by Forbes and Tyndall, who successively pursued their researches for many years among the Glaciers, with unwearied diligence and rare scientific skill. Professor Tyndall succeeded, too, in demonstrating, by actual experiment, that the surface of a Glacier, like that of a river, moves more rapidly than its lower strata. But not content with proving what was before known or conjectured, this indefatigable observer has established a new and curious analogy between the motion of a Glacier and of a river.

When a river flows through a winding channel, the point of most rapid motion is not exactly in the centre of the stream. It shifts, at every bend, from one side of the centre to the other, so as to be always a little on the convex side of the curve. Now, the valley-bed of the Mer de Glace is a winding channel, through which the ice-stream flows. By fixing a line of stakes, at short intervals from one another,

across the Glacier, Professor Tyndall was able to measure the exact motion of every part. And he found invariably that, at each bend of the valley, the stake which advanced most rapidly was a little distance from the centre, and always on the convex side of the Glacier curve.

Moraines of a Glacier.—Though the Glaciers of the Alps take their origin from snow fields of dazzling whiteness they do not long preserve unsullied their spotless purity of colour. The forces of Nature are unceasingly at work on the mountains that flank them at either side. Mighty rocks are rent asunder by the frost; lofty cliffs are shattered by the lightning; loose shingle and mud are washed down by the torrent: and all this ruin is heaped up, from day to day, and from year to year, on the surface of the Glacier. The lighter materials are scattered about in all directions by the wind, and envelop the Glacier in a vesture of dingy brown. But the larger and denser masses of debris remain, for the most part, near the foot of the mountains, and form, at each side of the Glacier, a long and lofty pile which is borne slowly down towards the plain below. These ramparts of rock and shingle and mud are called Lateral Moraines; and I know hardly any object of more striking interest in the natural history of our globe.

Standing in the lonely recesses of a Glacier the traveller hears, at intervals, the rattle of the loose shingle down the mountain side, and he sees the fragments, sometimes one by one, sometimes in a cluster, like a shower of rockets, leap out upon the ice, to begin their long and tedious but inevitable journey to the valley below. Now and then a massive rock is let loose which, leaping from crag to crag, comes down at

length with a crash to take its place among its fellows on the moraine; or perhaps it is caught on a projecting ledge, and its journey delayed for years.

Now, we must realise to our minds that this process, which we may witness for half an hour, once and again, is going on, not for hours only, or for days, but for years and for centuries; and thus we shall come to form a picture of what Nature is really about, in the wild solitudes of the Glaciers, unheeded and even unseen, except at rare intervals, by human eye. She is hewing her mountains to pieces, and carrying away the ruins, by a machinery of her own, to distant sites, where she is minded, no doubt, to use them for other purposes, which may be to us an object of speculation and wonder, but which we can hardly hope fully to comprehend.

When two Glaciers meet, they unite like the tributaries of a river, and move on together down the valley. In such a case it is evident that the two adjacent lateral moraines of the two Glaciers will come together at the point of junction, and thenceforth form one united ridge of rock and rubbish. This ridge is called the Medial, or Middle Moraine. When there are three tributary Glaciers there will be, of course, two medial moraines: one formed at the junction of the first and second Glaciers, the other at the junction of the second and third. And so, in every case, each new tributary involves the production of a new medial moraine. These medial moraines, which may be readily distinguished when we look up the valley from below, constitute a very characteristic feature of Glacier phenomena. They appear as long barriers of rock, roughly parallel to the sides of the valley, and

mark out definitely the several tributaries of which a great trunk Glacier is composed.

Every Glacier wastes away at its lower end, by the melting of the ice; and, as it wastes away, it deposits on the floor of the valley the mass of rock and shingle and mud which it has borne down from the higher mountains. The waste, however, is, for the most part, made good by the onward march from behind; and thus the actual position of the end of the Glacier may remain unchanged for many years together. Meanwhile, the portion that disappears each year adds a fresh contribution to the pile of rock and ruin, which thus grows up into a great barrier stretching across the valley. This barrier is called the Terminal Moraine of the Glacier.

Sometimes, however, the yearly waste of the Glacier is greater than the compensation made by its onward march; and then the Glacier diminishes in size and shrinks backward up the valley, leaving its terminal moraine behind. Many such terminal moraines may be seen, at the present day, in Switzerland, covered with vegetation, and separated sometimes by pasture fields, and even by villages, from the Glaciers by which they were deposited. On the other hand, when the snowfall, for a number of years, has been unusually great, and the summers unusually cold, then the compensation exceeds the waste; the Glacier moves farther down the valley, carrying before it human dwellings, tearing up forest trees, and even pushing along, with gentle but resistless force, the mountain-like pile of its own terminal moraine.

Crevasses.—Another interesting feature of the Glacier consists in those deep clefts or fissures by which it is inter-

sected in all directions, and which are generally known by the French name of Crevasses. The crevasse first appears as a minute crack in the surface of a Glacier, into which you could, with difficulty, introduce the blade of a penknife. In a few days this crack is, perhaps, an inch wide: later on, it is a foot across; and so it continues to increase until it becomes, at length, a yawning chasm of unknown depth, several feet in width, and, it may be, a hundred yards, or more, in length.

Chasms of this kind constitute one of the difficulties and dangers of Glacier excursions. In summer, below the snow line, the surface of the Glacier is usually free from snow, and you can see the chasm as you approach. It is then little more than an obstacle in your way, and involves no real danger. If it is narrow, you can step across; if it is too wide for leaping, you will often find a colossal mass of rock, caught in the jaws of the crevasse, which affords a convenient bridge over which you may pass in safety. At the worst, you can follow the edge of the chasm, which must come to an end somewhere, and thus get round it, at the cost of a little time and trouble. But in the higher regions, where the Glacier is covered with snow, the crevasse, even in summer, is a great source of danger, and has proved the grave of many a bold mountaineer.

The whole surface is here an unbroken field of snow; and the treacherous chasm is concealed from the traveller's eye until he steps into it, and is lost. Nevertheless, a remedy has been found for this danger, and we are assured by the most experienced guides that none need suffer except from their own neglect. A single traveller has, indeed, no

security. But a party of four or five, with a rope passing from one to the other, firmly secured to each, leaving an interval of ten or twelve feet between, is held to be perfectly safe. One of the party may step into a hidden crevasse, and disappear for a moment, but his companions, who have firm footing on the solid Glacier, are at hand to pull him out. No doubt there are many who might not like even this temporary acquaintance with the interior of a crevasse; and I suppose the best security for them is to keep carefully, in their excursions, below the limits of perpetual snow.

FIG. 49.

THE USE OF THE ROPE ON A GLACIER.

The records of Alpine adventure are full of catastrophes, due to the recklessness of young mountaineers in neglecting the use of the rope. Here is one example taken from many. On the ninth of August, 1864, two Austrian travellers made the ascent of Mont Blanc, accompanied by two guides and three porters. In descending the mountain, the youngest of the porters, who had made the ascent for the first time, elated with his success, refused to be attached to the rope, and went on before the rest of the party. On reaching the edge of a long crevasse, which was covered by a bridge of snow, he tested it with his foot, and thinking it

strong enough to bear his weight, stepped forward, and disappeared on the instant, leaving only a hole in the snow bridge, just the size of his body.

The guides at once declared that all hope of saving the life of their unfortunate companion was out of the question, and they hastened back, with the rest of the party, to Chamouni. On the same night, a body of fifteen guides, who volunteered for the service, was organized and equipped, to go in search of the dead body. They left Chamouni at midnight, and reached the scene of the disaster the next morning, at eleven o'clock. One of the most devoted of the party, Michel Payot, fastened a girdle of strong leather to his body, to which were attached two ropes, and he was lowered into the crevasse. He descended to a depth of a hundred and fifty feet without coming to the bottom, or finding any trace of the body; and at length, at a signal agreed upon, he was drawn back to the surface, quite exhausted from cold and fatigue.[1]

The Bergschrund.—A Bergschrund is the name given to a crevasse of large dimensions, which is generally found where the Glacier approaches the mountain, or where it skirts the foot of a deep gully descending from one side or the other of its main track. It is a great impediment to travellers, but not so treacherous as the snow-covered crevasse, because an experienced mountain climber can generally estimate pretty accurately the position of the Bergschrunds. In the early part of summer, they are often well bridged over with ice or snow, and may be easily passed in safety. But in the month

[1] See Les Fastes du Mont Blanc, pp. 207–11.

Fig. 50.—Crossing a Bergschrund on an Ice Bridge.

of August, when the bridges have been, in great part, melted away by the action of the sun, they offer not unfrequently a perfectly impassable barrier. The adjoining sketch, for which I am indebted to the kindness of Mr. Whymper, gives a very good idea of a Bergschrund and the way of crossing it on an ice bridge.

In descending a mountain, it is often practicable to leap across a Bergschrund, even of considerable dimensions. As the upper edge usually juts forward over the chasm, like a projecting cornice, the feat is much less perilous than it would seem to be, at first sight; and it may be accomplished in safety even by mountaineers who are not quite of the first rank. Here is an amusing account of such a performance from the picturesque pen of Mr. Whymper.

"We commenced to descend towards the Glacier de Pilatte by a slope of smooth ice, the face of which, according to the measurement of Mr. Moore, had an inclination of 54°! Cros still led, and the others followed at intervals of about fifteen feet, all being tied together, and Almer occupying the responsible position of last man: the two guides were therefore about seventy feet apart. They were quite invisible to each other from the mist, and looked spectral even to us. But the strong man could be heard by all hewing out the steps below, while every now and then the voice of the steady man pierced the cloud,—'Slip not, dear Sirs; place well your feet: stir not until you are certain.'

"For three quarters of an hour we progressed in this fashion. The axe of Cros all at once stopped. 'What is the matter, Cros?' 'Bergschrund, gentlemen.' 'Can we get over?' 'Upon my word, I don't know; I think we

must jump.' The clouds rolled away right and left as he spoke. The effect was dramatic. It was a *coup de théâtre*, preparatory to the 'great sensation leap' which was about to be executed by the entire company.

"Some unseen cause, some cliff or obstruction in the rocks underneath, had caused our wall of ice to split into two portions, and the huge fissure which had thus been formed extended, on each hand, as far as could be seen. We, on the slope above, were separated from the slope below by a mighty crevasse. No running up and down to look for an easier place to cross could be done on an ice-slope of 54°; the chasm had to be passed then and there.

"A downward jump of fifteen or sixteen feet, and a forward leap of seven or eight feet had to be made at the same time. That is not much, you will say. It was not much; it was not the quantity, but it was the quality of the jump which gave to it its particular flavour. You had to hit a narrow ridge of ice. If that was passed, it seemed as if you might roll down for ever and ever. If it was not attained, you dropped into the crevasse below, which, although partly choked by icicles and snow that had fallen from above, was still gaping in many places, ready to receive an erratic body.

"Cros untied Walker, in order to get rope enough, and warning us to hold fast, sprang over the chasm. He alighted cleverly on his feet; untied himself and sent up the rope to Walker, who followed his example. It was then my turn, and I advanced to the edge of the ice. The second which followed was what is called a supreme moment. That is to say, I felt supremely ridiculous. The world seemed to

revolve at a frightful pace, and my stomach to fly away. The next moment I found myself sprawling in the snow, and then, of course, vowed that it was nothing, and prepared to encourage my friend Reynaud.

"He came to the edge and made declarations. I do not believe that he was a whit more reluctant to pass the place than we others, but he was infinitely more demonstrative—in a word, he was French. He wrung his hands. 'Oh! what a *diable* of a place!' 'It is nothing, Reynaud,' I said, 'it is nothing.' 'Jump,' cried the others, 'jump.' But he turned round, as far as one can do such a thing in an ice-step, and covered his face with his hands, ejaculating, 'Upon my word, it is not possible. No! no!! no!!! it is not possible.'

"How he came over I do not know. We saw a toe—it seemed to belong to Moore; we saw Reynaud a flying body, coming down as if taking a header into water; with arms and legs all abroad, his leg of mutton flying in the air, his bâton escaped from his grasp; and then we heard a thud as if a bundle of carpets had been pitched out of a window. When set upon his feet he was a sorry spectacle; his head was a great snowball; brandy was trickling out of one side of the knapsack, chartreuse out of the other—we bemoaned its loss, but we roared with laughter."[1]

A Crevasse yielding up its Victims.—The bodies of those who are lost in crevasses are often imbedded in the ice, and being thus preserved from decomposition, are given up many years afterwards, in a state of perfect preservation, at the

[1] Scrambles amongst the Alps, pp. 228–30.

FIG. 51.—LEAPING A BERGSCHRUND.

foot of the Glacier. I will give you one very interesting and perfectly authentic example of this curious phenomenon. In the month of August, 1820, Dr. Hamel, a Russian traveller, with two English companions, and a party of seven guides, attempted the ascent of Mont Blanc. They had reached in safety that magnificent expanse of snow known as the Grand Plateau, not far from the highest summit of the mountain, when they were caught in an avalanche, which swept three of the guides into a yawning crevasse.

Forty years passed away, and no tidings were ever heard of them: but on the fifteenth of August, 1861, far away in the valley, many miles from the scene of the catastrophe, their remains were given up, by the melting of the ice, at the end of the Glacier des Bossons. Arms, legs, and skulls, were successively brought forth to the light of day, the flesh being still quite white and adhering firmly to the bones. Near them were found fragments of clothes, the straw hat of one of the guides, the gauze veil of Dr. Hamel, a broken Alpen stock, and, perhaps most curious of all, a roast leg of mutton still in a good state of preservation. These and many other similar records of the sad catastrophe, having been gathered together, were carried to the office of the Mayor of Chamouni, and became the subject of judicial investigation.

The chief witness was Marie Couttet, one of the guides who had escaped, and who was now seventy-two years of age. The old man identified, without difficulty, all the various fragments spread out before him, and was deeply affected as each, in turn, brought vividly to his mind some incident of the perilous expedition. "This is the hat," he said, "of

Auguste Tairraz; it was he who carried the pigeons which we were to let fly from the summit; and see, here is the wing of one of them. This stick, shod with iron, is the remnant of my Alpen stock: I made it myself for my excursions on the Glaciers. And it saved my life; for when my companions were swallowed up I was supported on my staff, and remained suspended over the crevasse. It broke at last; but I was able to free myself from the snow, and I was saved. What joy to see it again!" "This is the hand of Balmat; I know it well." And kissing it tenderly, he added: "I could not have believed that, before leaving the world, it would have been granted to me to press once again the hand of my brave comrade, my good friend Balmat." Another surviving guide of the expedition, Julien Devouassoux, was also present at this strange scene. But he was upwards of eighty years of age; memory and intelligence were gone; and he looked on at the sad spectacle without emotion or apparent interest.[1]

The Ice Cascade.—The crevasse owes its origin to a straining of the Glacier as it moves along its valley-bed. We have seen that the motion is more rapid near the centre than at the sides. Thus a strain is established between the different parts of the Glacier. The hard and brittle ice cannot stretch, so it cracks across; and the cracks widen from day to day. Fissures arising in this way are chiefly confined to the margin of the Glacier; but there are others which stretch right across from side to side.

Suppose that, at a certain point, the valley makes a

[1] See the Procés Verbal of this investigation, given at length in Les Fastes du Mont Blanc, pp. 65–72.

sudden dip downwards. The Glacier moving over the floor of the valley is, in a manner, strained round the angle so made: just as I might take a straight strip of glass and strain it round the edge of this table. The glass, unable to yield by stretching, must yield by breaking: so, too, the Glacier, strained across a projecting angle of its rocky bed, cracks at its surface; and the strain continuing from day to day, the crack soon becomes a fissure, and the fissure a chasm. As each succeeding portion of the Glacier passes over the bend it is broken in like manner. Thus a succession of chasms is formed, with a great transverse wall of ice between each two.

These transverse walls are often broken up themselves, by local strains, into great blocks or crags. And when the dip of the valley amounts to a precipice, the whole surface of the Glacier, in such a locality, is rent and torn assunder, and assumes fantastic forms of towers, peaks, and pinnacles, which, glittering in the rays of the mid-day sun, present a scene of wild and indescribable splendour. This phenomenon is very frequent in the Alps. Seen from a distance it suggests the idea of a foaming cataract suddenly converted into ice. Hence it is called, not unfitly, an Ice Cascade.

The ice towers of the cascade, known in Switzerland by the name of *Séracs*, are exposed, in a special degree, to the action of the sun's heat; to which, indeed, is chiefly due the singular and fantastic forms they assume. In summer they are often undermined by the melting away of their foundations; and then they topple over, and come down with a tremendous crash, several hundred tons of ice being sometimes precipitated, with fearful violence, on the slopes

of the Glacier. This is called an Ice Avalanche; a well-known source of danger to Alpine travellers. Here is a lively account of one from which Mr. Whymper narrowly escaped a few years ago.

"We got to the rocks in safety; and if they had been doubly as difficult as they were we should still have been well content. We sat down, keeping our eyes fixed on the towering pin-

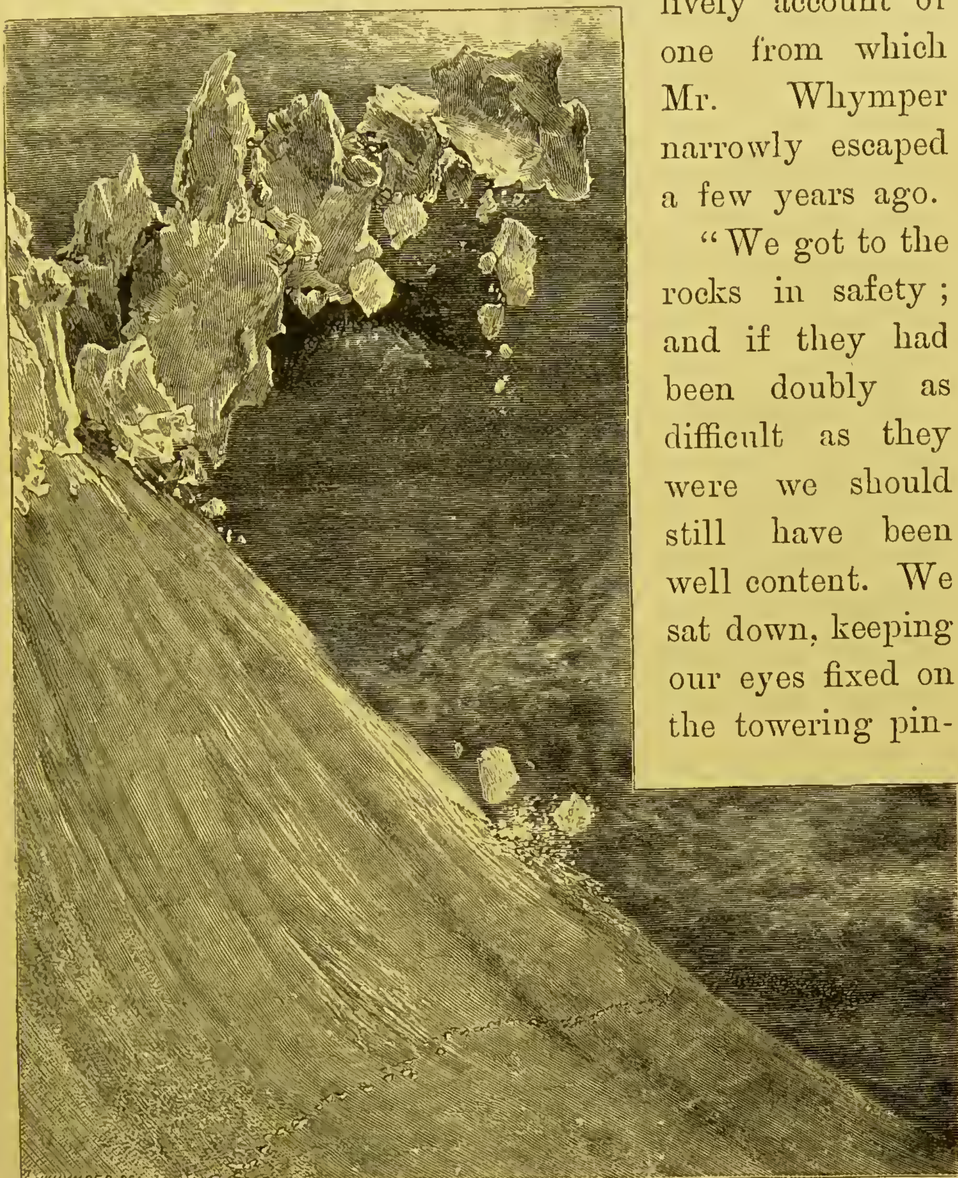

FIG. 52.—FALL OF AN ICE AVALANCHE.

nacles of ice under which we had passed; but which, now, were almost beneath us. Without a preliminary warning

sound, one of the largest, as high as the monument at London Bridge, fell upon the slope below. The stately mass heeled over as if upon a hinge, holding together until it bent 30° forwards; then it crushed out its base, and, rent into a thousand fragments, plunged vertically down upon the slope that we had crossed. Every atom of our track, that was in its course, was obliterated; all the new snow was swept away, and a broad sheet of smooth, glassy ice, showed the resistless force with which it had fallen."[1]

The Snow Avalanche.—Still more terrible and destructive are the avalanches of snow, which descend further down the valleys, and not unfrequently overwhelm whole villages. They are of two kinds: the sliding avalanche, and the rolling avalanche. The sliding avalanche somewhat resembles a landslip. It generally originates from a layer of fresh snow lying on a steep slope of ice. You can easily imagine that, at a certain inclination of the slope, the snow is just balanced between the force of gravity which tends to make it slide, and friction which tends to prevent it from sliding. In such circumstances, the slighest disturbance—a peal of thunder, for instance, the light tread of the chamois, even, it is said, the voice of a passing traveller—may be sufficient to dislodge it from its bed. Thus the whole mass begins to slide; and acquiring force as it moves, it sweeps down into the valley, carrying everything before it. An avalanche of this kind was started by Mr. Whymper and his party, in his descent from the Grandes Jorasses.

[1] Whymper's Scrambles amongst the Alps, p. 258.

"The slopes were steep, and covered with new-fallen snow, flour-like, and evil to tread upon. On the ascent we had reviled it, and made our staircase with much caution, knowing full well that the disturbance of its base would bring down all that was above. In descending, the bolder spirits counselled trusting to luck and a glissade; the cautious ones advocated avoiding the slopes, and crossing to the rocks on their farther side. The advice of the latter prevailed, and we had half traversed the snow, to gain the ridge, when the crust slipped, and we went along with it. 'Halt!' broke from all four unanimously. The axe-heads flew round as we started on this involuntary glissade. It was useless: they slid over the underlying ice fruitlessly. 'Halt!' thundered Cros, as he dashed his weapon in again with superhuman energy. No halt could be made, and we slid down slowly, but with accelerating motion, driving up waves of snow in front, with streams of it hissing all around. Luckily the slope eased off at one place; the leading men cleverly jumped aside out of the moving snow, we others followed, and the young avalanche which we had started, continuing to pour down, fell into a yawning crevasse, and showed us where our grave would have been, if we had remained in its company five seconds longer. The whole affair did not occupy half a minute."[1]

The rolling avalanche begins with a very small quantity of snow, dislodged from its place on some mountain crest, and sent rolling down the slopes of the snow fields. As it rolls along, it gathers, at every turn, fresh snow round itself, and rapidly grows from the size, perhaps, of a pea to the size of

[1] Whymper's Scrambles amongst the Alps, p. 345.

a snowball, from the size of a snowball to the size of a cottage, from the size of a cottage to the size of a mountain; and then rushing into the valley with enormous velocity, carries death and destruction in its path. I will give you one or two examples of its power.

In the year 1749, the village of Tawich, in the canton of the Grisons, was completely buried under an avalanche of this kind. A hundred persons were afterwards dug out from beneath the snow: but of these only two were alive. In the same canton, an avalanche came down, in the year 1806, and carried a forest from one side of the valley to the other, planting a fir-tree on the roof of the parsonage house. Again, in the year 1820, at Obergesteln, near the Glacier of the Rhone, four hundred head of cattle and eighty human beings were overwhelmed in an avalanche of snow.

The Glacier returns to its parent Ocean.—But it is time to return to the history of the Glacier, and follow it out to the end. We have seen that the Glacier is fed from the snow-fields, and the snow-fields are the products of the clouds that sweep across the Alps; and the clouds are only the vapour of the atmosphere, first condensed into water, and then crystallized into snow; and the vapour of the atmosphere has been drawn off from the ocean by the action of the sun's heat: and now it remains for me only to tell you how the Glacier itself returns again to its parent ocean, and thus completes the cycle of its history.

The lower end of every Glacier is the source of a river, which rushes out from beneath a massive vault of ice. This river is fed partly by the melting of the ice at the end of the

Glacier, partly by the melting that goes on over its surface the whole summer through. Every traveller knows that a Glacier is traversed in summer with numerous rills, which make for themselves little furrows in the ice, often uniting so as to form considerable streams, and flowing down over the surface until they come to the edge of a crevasse, into which they plunge and disappear. All these rills and streams find their way, through the ice, to the floor of the valley, and then continuing their course, underneath the Glacier, issue at length from the vaulted arch at the end.

The river thus brought into existence is, therefore, nothing less than the Glacier itself, under a new form, and entering on a new career. It is saturated with fine mud, derived from the moraines, or produced by the grinding action of the Glacier against its valley-bed; and when first we see the turbid, muddy stream into which the exquisite blue ice of the Glacier has been converted, we can hardly suppress a feeling of disappointment and regret. But the beauty of the Glacier has not been wholly effaced: it has been only veiled for a time. If we follow the stream in its course we shall find that it throws down its muddy garb in the first great lake through which it flows; and we may recognise, once again, the beautiful tints of the Glaciers of the Alps in the blue waters of the Swiss and Italian Lakes—of Geneva, Constance, Lucerne, Garda, Maggiore, and Como. After a brief interval of repose in these great basins, the Glacier streams set out once more on their long journey, and under the familiar names of the Rhine, the Rhone, the Po, the Adige, the Inn, stretch away in all directions, for hundreds of miles, across the continent of Europe, never halting on the

way till they pour back the melted snow-fields of the Alps into the Northern Ocean, the Black Sea, and the Mediterranean.

A Record inscribed on the Rocks.—Thus we learn that the Glaciers of the Alps represent but one particular stage in a long series of changes, which go on unceasingly from age to age. The Glaciers of to-day are the clouds of yesterday, and the rivers of to-morrow. They spring from the ocean, and to the ocean they return again. But during the period of their existence they inscribe a record of themselves on the rocks of the valleys over which they pass. This record may be deciphered by a keen eye, and interpreted by a trained intelligence: and perhaps you will kindly bear with me if, before bringing my Lecture to a close, I try to give you some idea of the nature of the record and of the story it unfolds.

The Glacier, in moving down a valley, has a singular power of polishing and scoring its rocky bed. Fragments of rock, angular stones, and fine sand, fall through the crevasses and get firmly imbedded in the under surface of the Glacier, sharing its motion, and accordingly, grating, under enormous pressure, against the floor of the valley. Thus the Glacier practically becomes a powerful grinding machine, under the action of which the rocks of the valley soon lose their projecting angles, and receive a smooth and polished surface. At the same time, this smooth surface is, here and there, deeply furrowed by angular blocks of some hard mineral, such as quartz, which, like a graver's tool, cuts into the softer material of the rock below. And again, the hard, fine sand, rubbing against the polished surface of the rock,

leaves its mark in the form of fine scratches, or striæ, as they are called, the direction of which always corresponds to the direction in which the Glacier is moving.

These markings are now universally recognised as characteristic of Glacier action; they are invariably produced by Glaciers, and are produced by no other known physical agent. They may be studied with special advantage, at the present moment, in Switzerland: for, during the last fifteen years most of the Swiss Glaciers have been shrinking backwards up their valleys. Hence, the surface lately covered by these Glaciers is now exposed to view, and the impressions they have left behind on the rocks may be easily discerned and observed at leisure. A few days spent near the edge of the Mer de Glace, or of the Glacier of the Aar, or, indeed, of almost any Swiss Glacier, will be sufficient to train the eye to recognise, at a glance, these characteristic records of Glacier action: and then a new world of thought is suddenly opened to the mind.

Taking, for example, the Glacier of the Aar, which is, perhaps, the best illustration I can select, we soon find that the characteristic markings I have described are not confined to the immediate neighbourhood of the present Glacier, but are plainly visible all the way down to the Grimsel Hospice, a good hour's walk from the nearest ice. Nay, passing the Grimsel Hospice, we can trace them down the valley of Hasli, and even as far as Meyringen and Brienz, twenty miles away.

We have here the record of the past and the work of the present, so to say, in one continuous scroll. Standing by the existing Glacier, we study carefully and

minutely the kind of grinding and carving which it has executed on the surface of the rocks in our own day. All down the valley we find the surface of the rock sculptured and polished in exactly similar fashion. And ascribing the same effect to the same cause, we conclude that an enormous Glacier once moved down the valley of Hasli, and left this curious record of its existence inscribed upon the rocks.

In like manner, if we followed the course of the Rhone, from its present source in the Rhone Glacier, we could trace out the same characteristic markings on the mountain walls and rocky floor of the valley, until they are lost, at length, in the lake of Geneva; and we could hardly resist the conclusion that the present Glacier of the Rhone is but a small fraction of a far mightier Glacier that once filled the whole valley to a distance of eighty miles. On crossing to the southern slopes of the Alps, we could easily discern similar evidence of an ancient Glacier in the valley of Aosta, and trace it out from its source in the snow-fields of Mont Blanc, through the vineyards and corn-fields of Piedmont, to the distant town of Ivrea.

Our conclusion does not rest on the evidence of Glacier markings alone. In all the cases I have mentioned, and in many others I might adduce, we should find, here and there, long, irregular mounds of earth and stones, sometimes barren and desolate, sometimes covered with vegetation, and studded with human habitations. These mounds, when carefully examined, are found to be the exact counterpart of the moraines, which, as we have seen, are left behind by every Glacier, when it shrinks in size, and retreats towards its source. Thus these massive piles become silent monuments,

testifying to the existence of ancient Glaciers, and confirming the record that has been carved upon the rocks.

It would be impossible, in a brief sketch, to give you an adequate conception of the force of this argument when mastered in all its details. I trust, however, that enough has been said to furnish some idea of the kind of reasoning which brings home to a geologist the conviction that the ancient Glaciers of Switzerland far exceeded in extent those of the present day.

Ancient Glaciers of the British Isles.—But the geologist does not stop here. Having by long and varied practice trained his eye and cultivated his judgment, in the country of existing Glaciers, he soon discovers that the traces of moving ice are to be found in other lands where Glaciers have been unknown within historic times. He finds, in fact, that he has learned a new language in which he can read some curious chapters in the past history of our globe. He tells us, for example, with unhesitating confidence, that the British Islands had their Glaciers and their snow fields in ancient times, just as Switzerland has her Glaciers and her snow fields to-day. And if we ask him for proof of this startling assertion, he takes us to the Glaciers of the Alps, and teaches us to read and understand the records they are now leaving inscribed on the valleys of Switzerland; and then he shows us these same records in the valleys of the Scottish Highlands, of Cumberland, and of Wales.

In Ireland, too, he might take us to the mountains of Kerry, and, by the aid of the same memorials, trace out the course of ancient Glaciers amidst the picturesque beauties of Killarney, and the Black Valley, and the Purple Mountain.

Or, coming nearer home, he might take us a ramble over that beautiful amphitheatre of hills that encircle our own city, and there point out those rounded domes of granite, those singular furrows and parallel scratches on the rocks, which reveal to his practised eye the existence of Glaciers in ages long gone by, as clearly as the scribblings on the walls of Pompeii reveal to the historian the gossip of society in the days of Imperial Rome.

Conclusion.—I have now exhausted the limits of my time, and I fear I have exhausted, too, the limits of your patience; but I am far from having exhausted the limits of my subject. I have sought only, in this hurried sketch, to put before you the leading features of a great natural phenomenon, and to give you some idea of the harmony and beauty of those laws which are concerned in its history. Of the majestic aspect which the Glaciers of the Alps present to the eye, and of the glorious scenery that surrounds them, I have attempted no description. For those who have been there description is unnecessary; and I could not help feeling that for those who have not been there all description is miserably inadequate.

But I venture to hope that in sketching out the laws to which these stupendous works of Nature owe their existence, their action, and their decay, I have suggested to you some new thoughts, and furnished a new source of pleasure. For I believe that scenery the most beautiful and sublime receives a new charm, when we are able not merely to contemplate the face of Nature, but to reach the intelligence behind; not merely to discern in her works that external beauty which strikes the eye, but to

trace out the evidence of wisdom, forethought, power, which leads the mind from the admiration of the material world to the knowledge and worship of Him who is the great Invisible Creator and Ruler of the universe.

APPENDIX.

APPENDIX.

RECENT CONTROVERSY ON LIGHTNING CONDUCTORS.

THE Lecture on Lightning Conductors contained in this Volume fairly represents, I think, the theory hitherto received on the subject. It is, moreover, entirely in accord with the Report of the Lightning Rod Conference, brought out, in 1883, by a Committee of most eminent men, representing several branches of science, who were specially chosen to consider this question, some ten years ago.

Lectures of Professor Lodge.—But, in the month of March, 1888, two Lectures were given before the Society of Arts, in London, by Professor Oliver Lodge, in which this theory was directly challenged, and attacked with cogent arguments, supported by striking and original experiments. These Lectures gave rise to an animated controversy, which culminated in a formal discussion at the recent meeting of the British Association in Bath. The discussion was carried on with great spirit, and most of the leading representatives of Physical and Mechanical Science took an active part in it. The greater portion of this volume was printed off before the meeting of the British Association took place. But the discussion on the theory of Lightning Conductors seemed to me so interesting and important that I thought it right, in the form of an Appendix, to give some account of the questions at issue, and of the opinions expressed upon them.

Professor Lodge maintains[1] that the received theory of Lightning Rods is open to two objections. First, it takes account only of the conducting power of the Lightning Rod, and takes no account of the phenomenon known as Self-induction, or Electrical Inertia. Secondly, it assumes that the whole substance of a Lightning Rod acts as a conductor, in all cases of Lightning discharge; whereas there is reason to believe that, in many cases, it is only a thin outer shell that really comes into action. I will deal with these two points separately.

The Effect of Self-Induction.—When an electric discharge begins to pass through a conductor, a momentary back Electro-motive force is developed in the conductor, which obstructs its passage. This phenomenon is called by some Self-induction, by others Electrical Inertia; but its existence is admitted by all. Now when a flash of Lightning, so to say, falls on a Lightning Rod, the back Electro-motive Force developed is very considerable; and it may offer so great an obstruction that the discharge will find an easier passage by some other route, such as the stone walls and woodwork, and furniture of the building.

According to this view, the obstruction which a flash of Lightning encounters in a Conductor consists partly of the resistance of the Conductor, in the ordinary sense of the word resistance, and partly of the back Electro-motive force due to Self-induction. The sum of these two Professor Lodge calls the Impedance of the Lightning Rod; and he considers that the Impedance may be enormously great, even when the resistance, in the ordinary sense, is comparatively small.

In support of this view he has devised he following extremely ingenious and remarkable experiment. A large Leyden Jar, L, was arranged in such a manner that, while it received a steady charge

[1] See his Lectures, published in The Electrician, June 22, June 29, July 6, and July 13, 1888.

from an electrical machine, it discharged itself, at intervals, across the air space at A, between two brass balls. The discharge had then two alternative paths before it: one through a conducting wire, C, the other across a second air space, between two brass balls at B. During the experiment, the two balls at A were kept at a fixed distance of one inch apart; but the distance between the two balls at

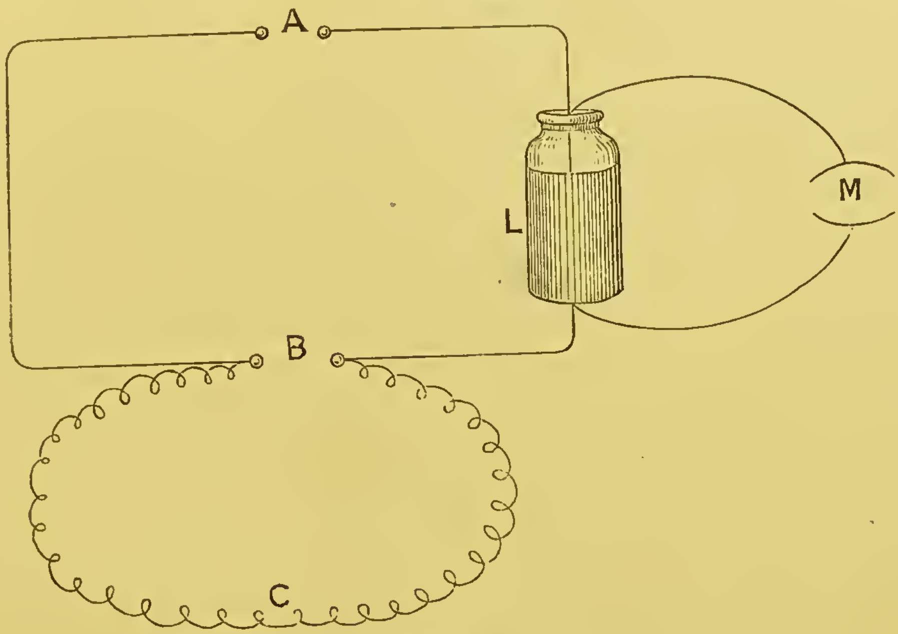

FIG. 53.

INDUCTION EFFECT OF LEYDEN JAR DISCHARGE.

M Electrical Machine.
L Leyden Jar.
A B Air Spaces between Brass Knobs.
C Conducting Wire.

B was varied. The conductor, C, used in the first instance, was a stout copper wire, about forty feet long, and having a resistance of only one-fortieth of an Ohm.

It was found that, so long as the distance between the B knobs was less than 1·43 inches, all the discharges passed across between the knobs, in the form of a spark. When the distance exceeded 1·43 inches, all the discharges passed through the conductor, C, and

no spark appeared between the balls at B. And when the distance was exactly 1·43 inches, the discharge sometimes took place between the knobs, and sometimes followed the conductor C. The interpretation given to these facts is that the obstruction offered by the conductor C was about equal to the resistance of 1·43 inches of air; and it is proposed to call this distance, under the conditions of the experiment, the *critical distance.*

Coming now to the application of these results, Professor Lodge argues that the conductor C, in his experiment, represents a Lightning Rod of unimpeachable excellence; and yet, in certain cases, the discharge refuses to follow the conductor, and prefers to leap across a considerable space of air, notwithstanding the enormous resistance it there encounters. In like manner, he says, a flash of Lightning may, in certain cases, leave a Lightning Rod fitted up in the most orthodox manner, and force its way to earth through resisting masses of mason work and such chance conductors as may come across its path.

This conclusion, he admits, is altogether at variance with the received views on the subject; but he contends that it is perfectly in accord with the scientific theory of an electrical discharge. The moment the discharge begins to pass in the conductor, it encounters the obstruction due to Self-induction; and this obstruction is so great that the bad conductors offer, on the whole, an easier path to earth.

Variation of the Experiment.—When the experiment was varied by substituting a thin iron wire for the stout copper wire at first employed, a very curious result was obtained. The wire chosen was of the same length as the copper, but had a resistance about 1300 times as great: its resistance being, in fact, 33·3 Ohms. Nevertheless, in this experiment, when the B knobs were at a distance of 1·43 inches, no spark passed, which showed that the discharge always followed the line of the conductor, and therefore that

the conductor offered less obstruction than 1·43 inches of air. The knobs were then brought gradually nearer and nearer; and it was not until the distance was considerably reduced that the sparks began to pass between them. When the distance was exactly 1·03 inches, the discharge sometimes passed between the knobs, and sometimes through the conductor: this was, therefore, the *critical distance*, in the case of the iron wire. Thus it appeared that the obstruction offered to the discharge by the iron wire was much less than that offered by the copper: the one being equal to a resistance of only 1·03 inches of air, the other to a resistance of 1·43 inches.

It does not appear that Professor Lodge undertakes to offer any satisfactory explanation of this result. He has come to the conclusion, from his various experiments, that, in the case of a sudden discharge, difference of conducting power, between fairly good conductors, is a matter of practically no account; and that difference of sectional area is a matter of only trifling account. But he does not see why a thin iron wire should have a *smaller* Impedance than a much thicker wire of copper. He proposes to repeat the experiments so as to confirm or to modify the result, which for the present seems to him anomalous.[1]

The outer Shell only of a Lightning Rod acts as a Conductor.— As a consequence of Self-induction or Electrical Inertia, Professor Lodge contends that a Lightning discharge, in a conductor, consists of a series of oscillations. These oscillations follow one another with extraordinary rapidity: there may be a hundred thousand in a second; there may be a million. Now it has been shown that, when a current starts in a conductor, it does not start at once all through its section; it begins on the outside, and then gradually, but rapidly, penetrates to the interior. From this he infers that the extremely rapid oscillations of a Lightning discharge have not

[1] See Paper read at the Meeting of the British Association, in Bath, 1888, published in The Electrician, September 14, p. 607.

time to penetrate to the interior of the conductor. The electricity keeps surging to and fro in the superficial layer or outer shell, while the interior substance of the rod remains inert and takes no part in the action. A conductor, therefore, will be most efficient for carrying off a flash of Lightning if it present the greatest possible amount of surface: a thin, flat tape will be more efficient than a rod of the same mass; and a number of detached wires more efficient than a solid cylinder. As for existing Lightning Conductors, the greater part of their mass would, in many cases, have no efficacy whatever in carrying off a flash of Lightning.

The Discussion.—The discussion at the Meeting of the British Association was opened by Mr. William H. Preece, F.R.S., Electrician to the Post Office, who claimed to have 500,000 Lightning Conductors under his control. He expressed his conviction that a Lightning Rod, properly erected and duly maintained, was a perfect protection against injury from Lightning; and in support of this conviction he urged very strongly the Report of the Lightning Rod Conference. This Report represented the mature judgment of the most eminent scientific men, who had devoted years to the study of the question; and he wished particularly to bring before the meeting their clear and decisive assertion—an assertion he was there to defend—that "there is no authentic case on record where a properly constructed Conductor failed to do its duty."

The new views put forward by Professor Lodge were based, in great measure, on his theory that a Lightning discharge consisted of a series of rapid oscillations. But this theory should be received with great caution. It seemed to be nothing more than a deduction from certain mathematical formulas, and was not supported by any solid basis of observation or experiment. Besides, there were many facts against it. They all knew that a flash of Lightning magnetized steel bars, deranged the compasses of ships at sea, and transmitted signals on telegraph wires. But such effects could not be produced

by a series of oscillations, which, being equal and opposite, would neutralize each other. It was alleged that these rapid oscillations occurred in the discharge of a Leyden Jar. That might be true, and probably was true; but they were not dealing with Leyden Jars, they were dealing with flashes of Lightning. If there was any analogy between the discharge of a Leyden Jar and a flash of Lightning, it was to be found, not in the external discharge employed by Professor Lodge in his experiments, but in the bursting of the glass cylinder between the two coatings of the Jar.

Lord Rayleigh thought the experiments of Professor Lodge were likely to have important practical applications to Lightning Conductors. But though these experiments were valuable as suggestions, they did not furnish a sufficient ground for adopting any new system of protection. It was only by experience with Lightning Conductors themselves that the question could be finally settled.

Sir William Thomson hoped for great fruit from the further investigation of Self-induction, in the case of sudden electrical discharges. He warmly encouraged Professor Lodge to continue his researches; but he expressed no decided opinion on the question at issue. Incidentally he observed that the best security for a gunpowder magazine was an iron house: no Lightning Conductor at all, but an iron roof, iron walls, and an iron floor. Wooden boards should, of course, be placed over the floor to prevent the danger of sparks from people walking on sheet-iron. This iron magazine might be placed on a dry granite rock, or on wet ground; it might even be placed on a foundation under water; it might be placed anywhere they pleased; no matter what the surroundings were, the interior would be safe. He thought that was an important practical conclusion which might safely be drawn from the consideration of these electrical oscillations and the experiments regarding them.

Professor Rowland, of the Johns Hopkins University, America, said that the question seemed to be whether the experiment of

Professor Lodge actually represented the case of Lightning. He was very much disposed to think it did not. In the experiment, almost the whole circuit consisted of good conductors; whereas, in the case of Lightning, the path of the discharge was, for the most part, through the air, and therefore it might be an entirely different phenomenon. The air being a very bad conductor, a flash of Lightning might, perhaps, not consist of oscillations, but rather of a single swing. Moreover, it was not at all clear that the length of the spark, in the experiment, could be taken as a measure of the obstruction offered by the conductor. Professor George Forbes was greatly impressed with the beauty and significance of Professor Lodge's experiments, but he did not think the result so clear that they should be warranted in abandoning the principles laid down by the Lightning Rod Conference.

M. de Fonvielle, of Paris, supported the views of Mr. Preece. He cited the example of Paris, where they had erected a sufficient number of Lightning Conductors, according to the received principles, and calamities from Lightning were practically unknown. He suggested that the Eiffel Tower, which they were now building, and which would be raised to the height of a thousand feet, would furnish an unrivalled opportunity for experiments on Lightning Conductors.

Sir James Douglass, Chief Engineer to the Corporation of Trinity House, had a large experience with Lighthouse towers. The Lightning Rods on these towers had been erected and maintained, during the last fifty years, entirely according to the advice of Faraday. They never had a serious accident: and such minor accidents as did occur, from time to time, were always traced to some defect in the Conductor. They had now established a more rigid system of inspection, and he, for one, should feel perfectly safe in any tower where this system was carried out.

Mr. Symons, F.R.S., Secretary to the Meteorological Society,

had taken part in a discussion on Lightning Conductors as long ago as 1859. It had been a hobby with him, all his life, to investigate the circumstances of every case he came across in which damage was done by Lightning; and the general impression left by his investigations entirely coincided with the views just expressed by Sir James Douglass. He had been a member of the Lightning Rod Conference, and was the Editor of their Report; and he wished to enter his protest against the idea of rejecting all that had hitherto been done in connection with Lightning Conductors, on the strength of mere laboratory experiments.

Professor Lodge, in reply, said he could perfectly understand the position of those who held that a Lightning Rod, properly fitted up, never failed to do its duty; because whenever it failed, they said it was not properly fitted up. The great resource, in such cases, was to ascribe the failure to bad earth contact. He thought a good earth contact was a very good thing, but he could not understand why such extraordinary importance should be attached to it. A Lightning Rod had two ends, an earth end and a sky end; and he did not see why good contact was more necessary at one end than at the other. If a few sharp points sticking out from the Conductor were sufficient for a good sky contact, why were they not sufficient also for a good earth contact?

Besides, though a bad earth contact might explain why a certain amount of disruption should take place at the earth, where the bad contact existed, he did not see how it accounted for the flash shooting off sideways, half-way down the Conductor. Again, what does a bad earth contact mean? If an electrical engineer finds a resistance of a hundred Ohms, he will rightly pronounce the earth contact to be very bad indeed. But why should the Lightning flash leave a Conductor with a resistance of a hundred Ohms, in order to follow a line of non-conductors where it encounters a resistance of many thousand Ohms?

He accepted the statement of Mr. Preece, that his whole theory depended on the existence of oscillations in the Lightning discharge: but there was good reason to believe they existed, because they were proved to exist in the discharge of a Leyden Jar. Mr. Preece objected that an oscillating discharge could not produce magnetic effects, as a flash of Lightning was known to do. He confessed he was unable to explain how an oscillating discharge produced such effects[1]: but that it could produce them there was no doubt whatever; for the discharge of a Leyden Jar produces magnetic effects, and we have ocular demonstration that the discharge of a Leyden Jar is an oscillating discharge.

As to the assurances we had received, from electrical engineers, that a properly-fitted Lightning Conductor never fails, he should like to ask them how the Hotel de Ville, in Brussels, had been set on fire by Lightning, on the first of last June. The system of Lightning Conductors on this building had been erected in accordance with the received theory, and had been held up, by writers on the subject, as the most perfect in Europe. Unless some explanation were forthcoming, to account for its failure, we could no longer regard Lightning Conductors as a perfect security against danger.

The President of Section A, Professor Fitzgerald, in bringing the discussion to a close, observed that one result of this meeting would be to give a new interest to the phenomena of static electricity and its practical applications. He was inclined himself to think that the experiments of Professor Lodge were not quite analogous to the case of a flash of Lightning. In comparing the discharge of a Leyden Jar with a flash of Lightning, they should look for the analogy, not so much in the external discharge through a series of conductors, but rather, as Mr. Preece had observed, in the bursting

[1] See a very ingenious hypothesis, to account for this phenomenon, suggested by Professor Ewing, in The Electrician, October 5, 1888, p. 712.

of the glass between the two coatings of the Jar. As regarded the oscillations in a Leyden Jar discharge, he did not think such oscillations were at all necessary to account for the phenomena observed in the experiments. Many of the results which Professor Lodge seemed to think would require some millions of oscillations per second, would be produced by a single discharge, lasting for a millionth of a second. Improvements, perhaps, were possible in our present system of Lightning Conductors; but practical experience had shown, however we might reason on the matter, that, on the whole, Lightning Conductors had been a great protection to mankind from the dangers of Lightning.

Summary.—I will now try to sum up the results of this interesting discussion, and state briefly the conclusions which, as it seems to me, may be deduced from it. First, I would remind my readers that a Lightning Rod has two functions to fulfil. Its first function is to promote a gradual, but rapid, discharge of electricity according as it is developed, and thus to prevent such an accumulation as would lead to a flash of Lightning: its second function is to convey the flash of Lightning, when it does come, harmless to the earth. Now the new views advanced by Professor Lodge in no way impugn the efficiency of Lightning Rods, as regards their first function; and it is evident that the greater the number of Lightning Rods distributed over a given area, the more perfectly will this function be fulfilled. This is a point of great practical importance, which seemed to me, in some degree, lost sight of during the progress of the discussion.

Secondly, it was practically admitted, by the highest authorities, that the experiments and reasoning of Professor Lodge afford good grounds for reconsidering the received theory of Lightning Conductors, as regards their second function, that of carrying the Lightning flash harmless to the earth. But there was undoubtedly a general feeling that it would be rash to set aside, all at once, the

received theory, on the strength of laboratory experiments, made under conditions widely different from those which actually exist in a Lightning discharge. Experiments are wanted on a larger scale; and, if possible, experiments with Lightning Rods themselves.

Thirdly, the testimony of electrical engineers, who have had large experience with Lightning Conductors, seems almost unanimous that a Lightning Conductor, erected and maintained in accordance with the conditions prescribed by the Lightning Rod Conference, gives perfect protection. It was certainly unfortunate that the Hotel de Ville, in Brussels, which was reputed the best protected building in Europe, should have been damaged by Lightning, just two months before the discussion took place: but no certain conclusion can be drawn from this catastrophe, until we know exactly the conditions under which it occurred.

So the matter stands, awaiting further investigation. /4

THE END.

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